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PHOSPHATES.

Phosphatic or Phosphoric Acid Fertilizers.

THE DIFFERENT SOURCES AND FORMS OF PHOSPHORIC ACID USED IN AGRICULTURE, AND THEIR METHODS OF PREPARATION AND APPLICATION.

By H. J. PATTERSON,
Director and Chemist of the Maryland Agricultural Experiment Station.

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PREFACE.

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The following Bulletin No. 94, by Prof. H. J. Patterson, Director and Chemist of the Maryland Agricultural Experiment Station, upon the preparation, action and use of Phosphatic Manures, is presented to the farmers of Pennsylvania, and commended to their careful attention and study.

The census of 1900 shows that there was expended in this State, in 1899, for commercial fertilizers, $4,686,080. This exceeds the amount expended in 1889 by $1,301,770, an increase of over $130,000 per year.

A large percentage of those who have purchased and are using these fertilizers are quite uninformed as to their effects on the soils and plants to which they are applied. This Department publishes, each year, analyses of all the brands found upon the markets in this State, and has also issued special bulletins upon the action and use of commercial fertilizers for the information of the farming community.

This work, by Director Patterson, is specially upon the action of phosphatic manures. These, as offered in our markets, are of various degrees of solubility, and contain varying percentages of phosphoric acid. Until comparatively recent, no exact experiments have been made to determine the comparative value of this fertilizer, as found in the untreated rock, compared with its effects in the more soluble forms. Director Patterson has been experimenting for several years in this direction, and gives, substantially, the results of his investigations in this bulletin.

All who use commercial fertilizers are, therefore, interested in the conclusions which he reaches, and by careful study of the experiments, will be better able to determine for themselves the best course to pursue in the application of phosphoric acid to their own soils.

JOHN HAMILTON,
Secretary of Agriculture

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INTRODUCTION.

Phosphates possess considerable interest to the agriculturist beyond their great importance in the every-day practical consideration of the means for maintaining and increasing the productive capacity of the land.

The foundation of the present system of agricultural chemistry was laid in connection with the study of the use of phosphates. The growth of agricultural chemistry, with the research based upon it, has brought about the development of the other sciences as related to agriculture and so produced all that may be encompassed by the term "Modern Scientific Agriculture." And phosphates may be said to be the initial of all that which may be hoped for as a result of the vast and world-wide efforts now being put forth in all classes of agricultural research.

HISTORICAL.

There is no definite record as to the time when the use of phosphates first came into existence, but as far as can be judged from the early records and writings upon agricultural topics, there seems to be but little doubt that the first commercial fertilizers ever used were chiefly phosphatic in their nature, and the good results which attended their application was mainly due to phosphoric acid.

From some notes of Varro it might appear that phosphates may have been used to some extent even B. C., but it is very sure, that even if such were the case, it was not until comparatively recent times that the value and need of phosphoric acid was actually recognized. Writers record that upon the first invasion of Britain by the Romans,

the natives were found using phosphatic marls to obtain better crops. But these practices were the result of accident or mere observation, and were not based upon any knowledge of the relations of soils, fertilizers and plants. The same is true of the practice of the Indians of putting fish in their hills of corn, as observed by the early settlers of America.

That there were no very definite ideas in the minds of the early users of phosphates or other mineral plant foods, at least ideas which correspond with the present existing theory of the relations of plants to mineral plant foods, is evidenced by the fact that the Prussian Academy of Sciences, in the year 1800, offered a prize for an investigation to decide whether the mineral matters found in plants are taken up from the soil or whether they are produced in the plants themselves by vital power. This question was treated by Schroader, whose decision was in favor of the latter opinion.

This opinion, though probably quite generally held, did not remain long in force, for Saussure, in 1804, declared that the mineral matter of humus contributed in a certain degree to fertility, since the same minerals are found in the ashes of plants. Sir Humphrey Davy was the first to consider the mineral constituents essential for the development of plants, as is evidenced by his statements in '*Elements of Agricultural' Chemistry*, London, 1814, to the effect that: "The chemistry of the simpler manures (the manures which act in very small quantities, such as bone dust, gypsum, alkalis and various saline substances), has hitherto been exceedingly obscure. It has been generally supposed that these materials act in the vegetable economy in the same manner as condiments or stimulants in the animal economy and that they render the common food more nutritive. It seems, however, a much more probable idea that they are actually a part of the true food of plants, and that they supply the kind of matter to the vegetable fiber which is analogous to the bony matter in animal stomachs." Springel, in his *Theory of Manuring*, published in 1839, was the second to express an opinion to this same effect. He said: "We can accept it as an indisputable fact that mineral matters found in plants are real nutrients for them, and that it is not their action upon humus which make them important, since gypsum, potassium, sulphate and calcium phosphate do not at all act upon the humus."

Closely following the statements of Springel, came (in 1840) the published results of the researches of Justus von Leibig. Leibig's results laid the foundation for our present agricultural chemistry, and entitled him to the designation of the "Father of Agricultural Chemistry."

While, as has been stated, mills for grinding bones existed early in the nineteenth century in France and England, and enterprising men went so far as to dig up battlefields and unearth thousands of tons of bones for agricultural purposes, and as it is even claimed that the credit for making the first super-phosphate is due to Sir James Murray, which was done in 1877, yet it was made without any real knowledge of the change which took place or application of the practical value accomplished.

As a result of his researches, Leibig pointed out that by treating bones and mineral phosphates with sulphuric acid, the insoluble phosphoric acid would be changed to a soluble form, and a considerable quantity of gypsum (sulphate of lime or land plaster), would be formed at the same time. The experiments of Leibig were substantiated by those conducted by the Duke of Richmond in comparing fresh and degelatinized bone from which he came to the conclusion that bones owed their fertilizing value not to gelatins or fatty matter, but to their large percentage of phosphoric acid. These experiments were still further confirmed by the results, shortly afterwards published by Boussingault. This set all uncertainty with regard to the value of phosphoric acid at rest and established its value and necessity on a permanent foundation, marked a distinct epoch in the uses of phosphates, which, from that time, has rapidly spread and been constantly increasing.

THE ROLE OF PHOSPHORIC ACID IN PLANTS.

The function which phosphoric acid performs in plants is quite varied, yet in all cases exceedingly essential. The present status of this subject has been fully set forth by Dr. Oscar Loew, in Bulletin No. 18, of the Division of Vegetable Pathology, U. S. Dept. of Agriculture, "On the Physiological Role of Mineral Nutrients." The principal points which it might be well to mention here are that the chlorophyll to which the green color of plants is due, can only be formed in the presence of phosphoric acid and, hence, all the essential functions which are closely related to the chlorophyll are dependent upon this element. Relatively large proportions are found in yeast cells, in seed just forming and numerous other microscopic organizations which are playing so important a part in the growth of plants. Proper embryo development of seeds seems to be dependent upon phosphates, and some observers have claimed that the total mass of protein in seeds is increased by an increased supply of phosphoric acid.

THE IMPORTANCE OF PHOSPHORIC ACID TO CROPS AND THE NEED FOR SUPPLYING IT IN FERTILIZERS.

It has already been stated that phosphoric acid was very necessary to the growth of crops and particularly essential to the maturity of seeds.

Though there is little loss of phosphoric acid from soils through any source except by crops, yet they draw on the soil to a considerable extent. The amount of phosphoric acid in various farm products and common products which farmers are familiar with is given in the following table, showing the fertilizing constituents:

TABLE 1.

METHOD OF MANUFACTURING SOLUBLE PHOSPHATES.

Compiled from Tables in Hand Book of Experiment Station Work, O. E. S. Bul. 15.

	Moisture—Per cent.	Ash—Per cent.	Nitrogen—Per cent.	Phosphoric acid—Per cent.	Potassium oxide—Per cent.
GREEN FODDERS.					
Corn fodder,	78.61	4.84	0.41	0.15	0.33
Sorghum fodder,	82.19	....	0.23	0.09	0.23
Rye fodder,	62.11	....	0.33	0.15	0.73
Oat fodder,	83.36	1.31	0.49	0.13	0.38
Common millet,	62.58	....	0.61	0.19	0.41
Japanese millet,	71.05	....	0.53	0.20	0.34
Hungarian grass (German millet),	74.31	....	0.39	0.16	0.55
Orchard grass (Dactylis glomerata),*	73.14	2.09	0.43	0.16	0.76
Timothy grass (Pleum pratense),*	66.90	2.15	0.48	0.26	0.76
Perennial rye grass (Lolium perenne),*	75.20	2.60	0.47	0.28	1.10
Italian rye grass ((Lolium italicum),*	74.85	2.84	0.54	0.29	1.14
Mixed pasture grasses,	63.12	3.27	0.91	0.23	0.75
Red clover (Trifolium pratense),	80.00	....	0.53	0.13	0.46
White clover (Trifolium repens),	81.00	....	0.56	0.20	0.24
Alsike clover, (Trifolium hybridum),	81.80	1.47	0.44	0.11	0.20
Scarlet clover (Trifolium incarnatum),	82.50	....	0.43	0.13	0.49
Alfalfa (Medicago sativa),	75.30	2.25	0.72	0.13	0.56
Cowpea,	78.81	1.47	0.27	0.10	0.31
Serradella (Orinthopus sativus),	82.59	1.82	0.41	0.14	0.42
Soja bean (Glycine soja),	73.20	....	0.29	0.15	0.53
Horse bean (Vicia faba),	74.71	....	0.68	0.33	1.37
White lupine (Lupinus albus),	85.35	....	0.44	0.35	1.73
Yellow lupine (Lupinus luteus).*	83.15	0.96	0.51	0.11	0.15
Flat pea (Lathyrus sylvestris),*	71.60	1.93	1.13	0.18	0.58
Common vetch (Vicia sativa),*	84.50	1.94	0.59	1.19	0.70
Prickley comfrey (Symphytum asperrinum),	84.36	2.45	0.42	0.11	0.75
Corn silage,	77.95	....	0.28	0.11	0.37
Corn and soja bean silage,	71.03	....	0.79	0.42	0.44
Apple pomace silage,*	75.00	1.05	0.32	0.15	0.40
HAY AND DRY COARSE FODDERS.					
Corn fodder (with ears),	7.85	4.91	1.76	0.54	0.89
Corn stover (without ears),	9.12	3.74	1.04	0.29	1.40
Teosinte (Euchlaena luxurians),	6.06	6.53	1.46	0.55	3.70
Common millet,	9.75	....	1.28	0.49	1.69
Japanese millet,	10.45	5.80	1.11	0.40	1.22
Hungarian grass,	7.69	6.18	1.20	0.35	1.30
Hay of mixed grasses,	11.99	6.34	1.41	0.27	1.55
Rowen of mixed grasses,	18.52	9.57	1.61	0.43	1.49
Redtop (Agrostis vulgaris),	7.71	4.59	1.15	0.36	1.02
Timothy,	7.52	4.93	1.26	0.53	0.90
Orchard grass,	8.84	6.42	1.31	0.41	1.88
Kentucky blue grass (Poa pratensis),	10.35	4.16	1.19	0.40	1.57
Meadow fescue (Festuca pratensis),	8.89	8.08	0.99	0.40	2.10
Tall meadow oat grass (Arrhenatherum avenaceum),	15.35	4.92	1.16	0.32	1.72
Meadow foxtail (Alopecurus pratensis),	15.35	5.24	1.54	0.44	1.99
Perennial rye grass,	9.13	6.79	1.23	0.56	1.55

TABLE 1—Continued.

	Moisture—Per cent.	Ash—Per cent.	Nitrogen—Per cent.	Phosphoric acid—Per cent.	Potassium oxide—Per cent.
Meadow foxtail (Alopecurus pratensis),	15.35	5.24	1.54	0.44	1.99
Perennial rye grass,	9.13	6.79	1.23	0.56	1.55
Italian rye grass,	8.71	....	1.19	0.56	1.27
Salt marsh hay,	5.36	....	1.18	0.25	0.72
Japanese buckwheat,	5.72	....	1.63	0.85	3.32
Red clover,	11.33	6.93	2.07	0.38	2.20
Mammoth red clover (Trifolium medium),	11.41	8.72	2.23	0.55	1.22
White clover,	....	....	2.75	0.52	1.81
Scarlet clover,*	18.30	7.70	2.05	0.40	1.31
Alsike clover,	9.94	11.11	2.34	0.67	2.23
Alfalfa,	6.55	7.07	2.19	0.51	1.68
Blue melilot (Melilotus caeruleus),	8.22	13.65	1.92	0.54	2.80
Bokhara clover (Melilotus alba),	7.43	7.70	1.98	0.56	1.83
Sainfoin (Onobrychis sativa),	12.17	7.55	2.63	0.76	2.02
Sulla (Hedysarum coronarium),	9.39	....	2.46	0.45	2.09
Lotus villosus,	11.52	8.23	2.10	0.59	1.81
Soja bean (whole plant),	6.30	6.47	2.32	0.67	1.08
Soja bean (straw),	13.00	....	1.75	0.40	1.32
Cowpea (whole plant),	10.95	8.40	1.95	0.52	1.47
Serradella,	7.39	10.60	2.70	0.78	0.65
Scotch tares,	15.80	....	2.96	0.82	3.00
Oxeye daisy (Chrysanthemum leucanthemum),	9.65	6.37	0.28	0.44	1.25
Dry carrot tops,	9.76	12.52	3.13	0.61	4.88
Barley straw,	11.44	5.30	1.31	0.30	2.09
Barley chaff,	13.08	....	1.01	0.27	0.99
Wheat straw,	12.56	3.81	0.59	0.12	0.51
Wheat chaff,	8.05	7.18	0.79	0.70	0.42
Rye straw,	71.61	3.25	0.46	0.28	0.79
Oat straw,	9.09	4.76	0.62	0.20	1.24
Buckwheat hulls,	11.90	....	0.49	0.07	0.52
ROOTS, BULBS, TUBERS, ETC.					
Potatoes,	79.75	0.99	0.21	0.07	0.29
Red beets,	87.73	1.13	0.24	0.09	0.44
Yellow fodder beets,	90.60	0.95	0.19	0.09	0.46
Sugar beets,	86.95	1.04	0.22	0.10	0.48
Mangel-wurzels,	87.29	1.22	0.19	0.09	0.38
Turnips,	89.49	1.01	0.18	0.10	0.39
Rutabagas,	89.13	1.06	0.19	0.12	0.49
Carrots,	89.79	0.22	0.15	0.09	0.51
GRAINS AND OTHER SEEDS.					
Corn kernels,	10.88	1.53	1.82	0.70	0.40
Sorghum seed,	14.00	....	1.48	0.81	0.42
Barley,*	14.30	2.48	1.51	0.79	0.48
Oats,	18.17	2.98	2.06	0.82	0.62
Wheat (spring),	14.35	1.57	2.36	0.70	0.39
Wheat (winter),	14.75	....	2.36	0.89	0.61
Rye,	14.90	....	1.76	0.82	0.54
Common millet,	12.68	....	2.04	0.85	0.36
Japanese millet,	13.68	....	1.73	0.69	0.38
Rice	12.60	0.82	1.08	0.18	0.09
Buckwheat,	14.10	....	1.44	0.44	0.21
Soja beans,	18.33	4.99	5.30	1.87	1.99
MILL PRODUCTS.					
Corn meal,	12.95	1.41	1.58	0.63	0.40
Corn-and-cob meal,	8.96	....	1.41	0.57	0.47
Ground oats,	11.17	3.37	1.86	0.77	0.59
Ground barley,	13.43	2.06	1.55	0.66	0.34
Rye flour,	14.20	....	1.68	0.85	0.65
Wheat flour,	9.83	1.22	2.21	0.57	0.54
Pea meal,	8.85	2.68	3.08	0.82	0.99

TABLE 1—Continued.

	Moisture—Per cent.	Ash—Per cent.	Nitrogen—Per cent.	Phosphoric acid—Per cent.	Potassium oxide—Per cent.
BY-PRODUCTS AND WASTE MATERIALS.					
Corn cobs,	12.09	0.82	0.50	0.06	0.60
Hominy feed,	8.93	2.21	1.63	0.98	0.49
Gluten meal,	8.59	0.73	5.03	0.33	0.05
Starch feed (glucose refuse),	8.10	....	2.62	0.29	0.15
Malt sprouts,	10.38	12.48	3.55	1.43	1.63
Brewers' grains (dry),	6.98	6.15	3.05	1.26	1.55
Brewers' grains (wet),	75.01	....	0.89	0.31	0.05
Rye bran,	12.50	4.60	2.32	2.28	1.40
Rye middlings,*	12.54	3.52	1.84	1.26	0.81
Wheat bran,	11.74	6.25	2.67	2.39	1.61
Wheat middlings,	9.18	2.30	2.63	0.95	0.63
Rice bran,	10.20	12.94	0.71	0.29	0.24
Rice polish,	10.30	9.00	1.97	2.67	0.71
Buckwheat middlings,*	14.70	1.40	1.38	0.68	0.34
Cotton-seed meal,	9.90	6.82	6.64	2.68	1.79
Cotton-seed hulls,	10.63	2.61	0.75	0.18	1.08
Linseed meal (old process),	8.88	6.08	5.43	1.66	1.37
Linseed meal (new process),	7.77	5.37	5.78	1.83	1.39
Apple pomace,	80.50	0.27	0.23	0.02	0.13
VEGETABLES.					
Artichokes,	81.50	0.99	0.36	0.17	0.48
Asparagus stems,	93.96	0.67	0.29	0.08	0.29
Beans, adzuki,	15.86	3.53	3.29	0.95	1.51
Beans, Lima,	68.46	1.69	....	....	....
Beans, string,	87.23	0.76	....	....	....
Beets, red,	88.47	1.04	0.24	†0.09	†0.41
Cabbages,	99.52	1.40	0.38	†0.11	†0.43
Carrots,	88.59	1.02	0.16	0.09	0.51
Cauliflower,	90.82	0.81	0.14	0.16	0.36
Chorogi, tubers,	78.90	1.09	1.92	0.19	0.64
Chorogi, whole plant,	78.33	1.02	....	....	....
Cucumbers,	95.99	0.46	0.16	0.12	0.24
Eggplant,	92.93	0.50	....	....	....
Horse-radish root,	76.68	1.87	0.36	0.07	1.16
Kohl-rabi,	91.08	1.27	0.48	0.27	0.43
Lettuce leaves,	86.28	1.71	....	....	....
Lettuce stems,	88.46	1.18	....	....	....
Lettuce, whole plant,	93.68	1.61	0.23	*0.07	*0.37
Muskmelons, interior juice,	91.62	1.01	....	....	....
Muskmelons, pulp,	76.44	1.49	....	....	....
Muckmelons, pulp juice,	90.53	0.56	....	....	....
Muskmelons, rind,	91.15	0.68	....	....	....
Mustard, white,	84.19	2.25	....	....	....
Okra,	87.41	0.74	....	....	....
Onions,	87.55	0.57	0.14	0.04	0.10
Parsnips,	80.34	1.03	0.22	0.19	0.62
Peas, Canada field,	12.48	2.36	....	....	....
Peas, garden,	12.62	3.11	3.58	0.84	1.01
Peas, green,	79.93	0.78	....	....	....
Peas, small (Lathyrus savitus), whole plant,	5.80	5.94	2.50	0.59	1.99
Pumpkins, flesh,	93.39	0.67	....	....	....
Pumpkins, rind,	86.23	1.36	....	....	....
Pumpkins, seeds and stringy matter,	76.86	1.51	....	....	....
Pumpkins, whole fruit,	92.27	0.63	*0.11	*0.16	*0.09
Rhubarb, roots,	74.35	2.28	0.55	0.06	0.53
Rhubarb stems,	92.67	0.94	....	....	....
Rhubarb, stems and leaves,	91.67	1.72	0.13	0.02	0.36
Rutabagas,	88.61	1.15	0.19	0.12	0.49
Spinach,	92.42	1.94	0.49	0.16	0.27
Squashes, flesh,	88.09	1.72	....	....	....

TABLE 1—Continued.

	Moisture—Per cent.	Ash—Per cent.	Nitrogen—Per cent.	Phosphoric acid—Per cent.	Potassium oxide—Per cent.
Squashes, rind,	82.00	1.21	....	....	....
Squashes, seeds and stringy matter,	74.03	1.39	....	....	....
Squashes, whole fruit,	94.88	0.41	....	....	....
Sweet corn, cobs,	80.10	0.59	0.21	0.05	0.22
Sweet corn, husks,	86.19	0.56	0.18	0.07	0.22
Sweet corn, kernels,	82.14	0.56	0.46	0.07	0.24
Sweet corn, stalks,	80.86	1.25	0.28	0.14	0.41
Sweet potatoes, tubers,	71.26	1.00	*0.24	*0.08	*0.37
Sweet potatoes, vines,	41.55	5.79	....	....	....
Tobacco,†	....	18.27	....	0.55	3.81
Tomatoes, fruit,	93.64	0.47	0.16	0.05	0.27
Tomatoes, roots,	78.31	11.72	0.24	0.06	0.29
Tomatoes, vines,	83.61	3.06	0.32	0.07	0.50
Turnips,	90.46	0.80	0.18	0.10	0.39
Watermelons, juice,	93.05	0.20	....	....	....
Watermelons, pulp,	91.87	0.33	....	....	....
Watermelons, rind,	89.97	1.24	....	....	....
Watermelons, seeds,	48.37	1.34	....	....	....
Apple leaves, collected in May,	72.36	2.33	0.74	0.25	0.25
Apple leaves, collected in September,	60.71	3.46	0.89	0.19	0.39
Apple, fruit,	85.30	0.39	0.13	0.01	0.19
Apple trees (young), branches,	83.60	0.65	....	0.04	0.04
Apple trees (young), roots,	64.70	1.59	....	0.11	0.09
Apple trees (young), trunks,	51.70	1.17	....	0.06	0.06
Apple trees (young), whole plant,	60.83	....	0.35	0.05	0.17
Apricots, dried,	32.44	1.38	....	....	....
Apricots, fresh,	85.16	0.49	0.19	0.06	0.29
Bananas, fresh,	66.25	1.15	....	....	....
Blackberries,	88.91	0.58	0.15	0.09	0.20
Blueberries,	82.69	0.16	0.14	0.05	0.05
Cherries, fruit,	86.10	0.58	0.18	*0.06	*0.20
Cherry trees (young), branches,	79.50	0.78	....	0.05	0.06
Cherry trees (young), roots,	67.20	1.22	....	0.08	0.07
Cherry trees (young), trunks,	53.20	0.81	....	0.04	0.06
China berries,	16.52	4.13	1.19	0.43	2.33
Cranberries, fruit,	89.59	0.18	....	0.03	0.09
Cranberries, vines,	....	2.45	....	0.27	0.32
Currants,	86.02	0.53	....	0.11	0.27
Grapes, fruit, fresh,	83.00	0.50	0.16	0.09	0.27
Grapes, fruit, dried and ground,†	34.83	1.16	....	....	....
Grapes, wood of vine,	....	2.97	....	0.42	0.67
Lemons,	83.83	0.56	0.15	0.06	0.27
Nectarines,	79.00	0.50	0.12	....	....
Olives, fruit,§	58.00	1.42	0.18	0.12	0.86
Olives, leaves,§	42.40	2.51	0.91	0.26	0.76
Olives, wood of larger branches,§	14.50	0.94	0.88	0.11	0.18
Olives, wood of small branches,§	18.75	0.96	0.89	0.12	0.20
Oranges, California,	85.21	0.43	0.19	0.05	0.21
Oranges, Florida,	87.71	....	0.12	0.08	0.48
Peaches, fruit,	87.85	0.32	....	0.05	0.24
Peaches, wood of branches,	58.26	1.93	0.90	0.22	0.50
Pears, fruit,	83.92	0.54	0.09	0.03	0.08
Pear trees (young), branches,	84.00	0.76	....	0.04	0.08
Pear trees (young), roots,	66.70	1.40	....	0.07	0.11
Pear trees (young), trunks,	49.30	1.71	....	0.07	0.13
Pineapples,	89.28	0.35	....	....	....
Plums,	47.48	0.54	0.18	0.02	0.24
Prunes,	77.38	0.49	0.16	0.07	0.31
Raspberries,	81.82	0.55	0.15	0.48	0.35
Strawberries, fruit,	90.84	0.60	0.15	0.11	0.30
Strawberries, vines,	....	3.34	....	0.48	0.35

TABLE 1—Continued.

	Moisture—Per cent.	Ash—Per cent.	Nitrogen—Per cent.	Phosphoric acid—Per cent.	Potassium oxide—Per cent.
Whortleberries,	82.42	0.41	....	....	....
Chestnuts, cultivated,	40.00	1.78	....	....	....
Chestnuts, native,	40.00	1.62	1.18	0.39	0.63
Chestnuts, Spanish,	10.00	2.66	....	....	....
Peanuts, hulls,	10.00	2.99	1.04	0.14	0.81
Peanuts, kernels,	10.00	2.21	4.01	0.82	0.88
Peanuts, vines after blooming,	10.00	12.36	....	0.20	0.90
Peanuts, vines before blooming,	30.00	7.45	....	0.32	1.16
WOOD.					
Ash wood,	10.00	0.32	....	0.012	0.149
Chestnut, bark,	10.00	3.51	....	0.114	0.278
Chestnut, wood,	10.00	0.16	....	0.011	0.029
Dogwood, bark,	10.00	9.87	....	0.140	0.341
Dogwood, wood,	10.00	0.68	....	0.057	0.190
Hickory, bark,	10.00	3.97	....	0.061	0.141
Hickory, wood,	10.00	0.48	....	0.058	0.138
Magnolia, bark,	10.00	2.98	....	0.095	0.192
Magnolia, wood,	10.00	0.36	....	0.032	0.071
Maple, bark,	10.00	9.49	....	0.421	1.197
Oak leaves, mixed,	....	4.70	....	....	....
Oak post, bark,	10.00	12.10	....	0.116	0.249
Oak post, wood,	10.00	0.77	....	0.070	0.163
Oak, red, bark,	10.00	6.29	....	0.103	0.179
Oak, red, wood,	10.00	0.57	....	0.060	0.140
Oak, white, bark,	10.00	5.95	....	0.074	0.125
Oak, white, wood,	10.00	0.26	....	0.025	0.106
Pine, burr,	....	1.09	....	....	....
Pine, Georgia, bark,	10.00	0.37	....	0.013	0.024
Pine, Georgia, wood,	10.00	0.33	....	0.012	0.050
Pine, old field, bark,	10.00	1.94	....	0.095	0.077
Pine, old field, wood,	10.00	0.18	....	0.007	0.008
Pine, straw, mixed,	....	1.65	....	....	....
Pine, yellow, wood,	10.00	0.23	....	0.010	0.045
Pine, black, wood,	10.00	0.21	....	0.009	0.030
Sycamore, wood,	10.00	0.99	....	0.121	0.230
ANIMAL PRODUCTS.					
Butter,	7.91	0.15	0.12	0.040	0.040
Buttermilk (85),	90.12	0.72	0.64	0.220	0.210
Cheese,	33.25	2.10	3.93	0.600	0.120
Cream,	74.05	0.50	0.40	0.150	0.130
Eggs,	67.20	6.18	2.18	0.370	0.150
Eggs without shell,	73.70	0.92	2.00	0.350	0.160
Fat renderings, cakes (5),	9.52	6.38	9.38	2.620	0.199
Calf,	66.20	3.80	2.50	1.380	0.240
Ox,	59.7	4.66	2.66	1.860	0.170
Sheep,	59.1	3.17	2.24	1.230	0.150
Swine,	52.00	2.16	2.00	0.880	0.180
Cow's milk,	87.00	0.75	0.53	0.190	0.180
Skim milk,	90.25	0.80	0.56	0.200	0.190
Skim milk, centrifugal separation (7),	9.60	0.74	0.49	0.210	0.200
Whey,	92.97	0.60	0.150	0.140	0.180
Wool, washed,	12.80	0.98	9.44	0.180	0.190
Wool, unwashed,	15.00	7.08	5.40	0.070	5.620

*Dietrich and Konig; Zusamensetzung und Vardaulichkeit der Futtermittel.
**Dietrich and Konig.
†Wolff.
§Average of 50 analyses made by H. J. Patterson.
†"Grape food."
§L. Paparelli: Etude chiue sur l'oliver, Montpelier, 1888.

From the figures in Table 1 may be determined the amount of phosphoric acid disposed of in the products sold off the farm.

The quantities of phosphoric acid contained in the usual unit of measure of the more common products, together with the valuation of the same upon the basis of the commercial value of fertilizers is given in the following table:

TABLE 2.

Quantity and Value of the Phosphoric Acid Contained in the more Common Farm Products.

(Calculated on the Basis of the Ordinary Unit of Measure.)

Number.	Kind and Quantity of Product.	Quantity of phosphoric acid—Lbs.	Value—Cts.*	Amount which contains $1.00 worth of phosphoric acid.
	GRAINS AND SEEDS.			
1	1 bushel barley, 48 lbs.,	0.38	1.9	52.6 bushels.
2	1 bushel buckwheat, 48 lbs.,	0.21	1.0	100.0 bushels.
3	1 bushel clover seed, 60 lbs.,	0.87	4.3	23.3 bushels.
4	1 bushel corn, 56 lbs.,	0.39	1.9	52.6 bushels.
5	1 bushel oats, 32 lbs.,	0.26	1.3	77.0 bushels.
6	1 bushel rye, 56 lbs.,	0.46	2.3	43.5 bushels.
7	1 bushel timothy seed, 45 lbs.,	0.53	2.6	38.5 bushels.
8	1 bushel wheat, 60 lbs.,	0.53	2.6	38.5 bushels.
	HAY AND STRAW.			
9	1 ton clover hay,	3.8	19.0	5.3 tons.
10	1 ton timothy hay,	5.3	26.5	3.8 tons.
11	1 ton rye straw,	2.8	14.0	7.1 tons.
12	1 ton wheat straw,	1.2	6.0	16.7 tons.
	VEGETABLES AND FRUITS (60 lbs. each).			
13	1 bushel apples,	0.006	....	3,333.0 bushels.
14	1 bushel cabbage,	0.066	....	303.0 bushels.
15	1 bushel grapes,	0.050	....	400.0 bushels.
16	1 bushel peaches,	0.030	....	667.0 bushels.
17	1 bushel pears,	0.015	....	1,333.0 bushels.
18	1 bushel potatoes,	0.042	*	476 bushels.
19	1 bushel strawberries,	0.066	....	303 bushels.
20	1 bushel tomatoes,	0.030	....	667 bushels.
21	1 bushel turnips,	0.060	....	333 bushels.
	ANIMAL PRODUCTS.			
22	1 tub butter, 100 lbs.,	0.04	0.002	500 tubs.
23	1 can cream,† 10 gals., 80 lbs.,	0.12	0.006	167 cans.
24	1 can milk, 10 gal., 88 lbs.,	0.17	0.008	125 cans.
25	1 crate of eggs, 12 doz., 18 lbs.,	0.07	0.004	286 crates.
26	1 bale wool, 100 lbs.,	0.07	0.004	286 bales.
27	1,000 lbs. steer,	18.6	0.930	....
28	1,000 lbs. of sheep,	12.3	0.615	....
29	1,000 lbs. of hogs,	8.8	0.440	....

*At the rate of 5 cents per pound.
†Cream testing 20 to 25 per cent. fat.

In order to present an idea of the amount of exhaustion of phosphoric acid by crop in a little different way from the above, calculations have been made of the quantity removed from one acre by a fair yield of some of the commoner products. These figures are presented in Table 3.

TABLE 3.

Approximate Quantity of Phosphoric Acid in the Product of One Acre of Sundry Farm Crops.

Estimated Crop.	Phosphoric acid—Lbs.	Value of phosphoric acid—Cts.	Quantity of dissolved South Carolina rock* to supply the phosphoric acid—Lbs.
Corn, 50 bushels,	16.0	80	115
Oats, 40 bushels,	10.4	52	74
Wheat, 25 bushels,	12.0	60	86
Potatoes, 150 bushels,	14.4	72	103
Tomatoes, 10 tons,	4.2	21	30
Clover hay, 2 tons,	22.4	112	160
Timothy hay, 2 tons,	27.6	138	197
Wheat straw, 1¼ tons,	5.5	28	40
Green fodder corn, 15 tons,	30.0	150	214

*Calculated on the basis of 14 per cent. available phosphoric acid.

The figures given in Table 3 are not intended to show the amount of phosphoric acid needed for the growth of the whole plant or crop, but simply what would be removed in the parts which are generally sold.

The quantities of phosphoric acid which are removed by one bushel of product or even by a crop from one acre as exhibited by the figures in the preceding table, in most cases seem to be very small and, indeed, almost insignificant, yet, when the fact is considered that most of the lands have been under cultivation for a considerable length of time, it will be seen that even these small amounts represent considerable when multiplied by 10, 20, 50 and even 100 or more crops. The figures which have been given in Tables 1, 2 and 3 will serve the purpose for each person to gain some idea of what is taking place in individual cases, but give little conception of the vastness of what is taking place in the State as a whole.

The annual drain of phosphoric acid from the farms of Pennsylvania, by the principal crops, is shown by the figures in Table 4. Though large as these figures seem, yet they represent but a part of what is taking place. The amount removed by over one million

dollars' worth of truck crops and small fruits annually sold from Pennsylvania farms is not accounted for in the table. Again, the live stock, poultry and eggs annually sold carry considerable phosphoric acid with them.

The total amount removed by the crops, as exhibited in Table 4, of 102,538,740 pounds would require, if it were to be replaced, over 366 thousand tons of standard (14 per cent.) dissolved phosphate rock. This would mean an expenditure of over three and one-half millions of dollars annually for this one plant food alone.

TABLE 4.

The Approximate Quantity of Phosphoric Acid Annually Removed from Pennsylvania Farms by the Principal Crops.

(Compiled from Yields of the Twelfth Census, 1900.)

Crops.	Bushels.	Pounds.	Phosphoric acid.	Pounds of phosphoric acid.
Barley,	197,178	9,464,524	0.79	74,769
Barley straw,		15,389,690	0.30	46,169
Buckwheat,	3,922,980	188,295,240	0.44	828,499
Buckwheat straw,		320,101,908	0.61	1,952,621
Corn grain,	51,869,780	2,904,707,680	0.70	20,332,953
Corn fodder,		5,809,415,360	0.29	16,847,304
Oats,	37,242,810	968,313,060	0.82	7,940,367
Oat straw,		1,646,132,202	0.20	3,292,264
Rye,	3,944,750	220,906,000	0.82	1,811,429
Rye straw,		375,540,200	0.20	751,080
Wheat,	20,632,680	1,237,960,800	0.89	11,004,851
Wheat straw,		2,104,533,360	0.12	2,525,440
Potatoes,	21,769,472	1,219,090,432	0.07	853,363
Sweet potatoes,	234,724	13,144,544	0.08	10,515
Onions,	347,806	19,477,136	0.04	7,790
Tobacco (lbs.),	41,502,620	41,502,620	0.55	228,264
Beans,	23,957	1,341,592	0.95	12,745
Peas,	6,363	356,328	0.84	2,993
Hay and forage (tons),	3,766,834	7,533,668,000	0.45	33,901,506
Total,				102,424,922

Before proceeding further, it will probably be well to devote a little space to the general consideration of the subject of phosphoric manures, the forms in which phosphoric acids exist, and various sources and methods of manufacture of the same.

Phosphoric Acid and phosphates:—Phosphorous compounds are absolutely necessary for the maturity of plants and the formation of seeds for their reproduction. It has been well established

that the salts of phosphoric acid, or phosphates, as they are called, are the only sources from which phosphorus of plants can be derived. Phosphoric acid is a combination of the element Phosphorus (P) with Oxygen gas (O). In phosphates, the phosphorus and oxygen unite in the proportion of two parts of the former to five of the latter, forming what is commonly designated as *phosphoric acid*, and this union is expressed by the sign or symbol $P_2 O_5$. Phosphorus, when uncombined with other elements, is a yellowish, waxy looking, solid substance. It is soft and can be cut as easily as ordinary bees-wax. It is very poisonous. It ignites easily, and, therefore, has to be kept under water. When phosphorus burns, it simply unites with the oxygen of the air, forming phosphoric acid ($P_2 O_5$).

Phosphoric acid usually occurs in the soil in combination with lime, magnesia, alumina and iron. These phosphates are all practically insoluble in water; that is, they are dissolved by pure water so slowly and to so slight an extent that they sustain no appreciable loss in the soil by drainage water. Hence, the quantity in the soil is diminished almost wholly through the agency of crops. The amount of phosphoric acid, even in a fertile soil, is comparatively small. A ton of good soil will contain about three pounds; many will contain less, and some considerably more. On this basis an acre of average soil would contain to the depth of 9 inches, about 4,500 pounds of phosphoric acid.

The character of the soil affects very considerably, the available condition of the plant food. One of the problems that confronts the farmer is to use such methods in soil management as will convert the plant foods which the soil contains into forms available for crops.

FORMS OF PHOSPHORIC ACID.

As has already been stated, phosphoric acid exists in soils in combination with lime, magnesia, alumina and iron, and it is in these same combinations in which it is found in the various sources, from which phosphates are manufactured. For the manufacture of fertilizer and in agriculture, the phosphate of lime is most highly prized and preferred.

IRON AND ALUMNIA PHOSPHATES.

This represents a large class of natural phosphates. They are insoluble in water, the same as the natural lime phosphate. They contain almost the same percentage of phosphoric acid as lime phosphates. They are not well adapted for the manufacture of soluble phosphates as the treatment with acid produces a sticky mass which is hard to dry and keep in a good condition.

FORMS OF PHOSPHATE OF LIME.

In manufacturing fertilizer from phosphate of lime the aim has been to change it from the insoluble condition to a soluble condition which would be more available to plants. In the natural and insoluble state, the phosphate exists in what is chemically known as *tri-calcium phosphate* (three-lime phosphate), and in the course of manufacture this is changed chemically so that, at the end of the operation there exists four kinds or combinations of calcium (lime) and phosphoric acid, which are as follows:

(1.) Soluble phosphate of lime, or mono-calcium phosphate.
(2.) Reverted phosphate of lime, or di-calcium phosphate.
(3.) Insoluble phosphate of lime, or tri-calcium phosphate.
(4.) Tetra-calcium phosphate, or four-lime phosphate.

(1) SOLUBLE PHOSPHATE OF LIME.

This is properly known under several other names as "Super-phosphate," "Super-phosphate of lime," "Acid phospahte," "Acid phosphate of lime," "Water-soluble phosphate," "Acid calcium phosphate," "Mono-calcium phosphate," and "One-lime phosphate." Phosphoric acid does not occur naturally in the soluble state.

Soluble phosphoric acid is made by treating bones or mineral phosphates with sulphuric acid (oil of vitriol.) The chemical change which occurs is practically as follows: Sulphuric acid and water being applied to the materials containing insoluble phosphates (tri-calcium phosphate), the sulphuric acid combines chemically with two parts of lime and forms sulphate of lime or gypsum (land plaster), while the water unites with the phosphoric acid and one part of lime, forming mono-calcium or soluble phosphate of lime. The substances being mixed, it is a natural chemical action or re action that takes place with the result stated. The total conversion of the insoluble to the soluble form, cannot be accomplished without using such an excess of sulphuric acid as would be injurious to seeds and roots of plants which would come in contact with the fertilizer, and also would make the fertilizer of such a mechanical condition as to be difficult to handle and apply. In practice, less acid is added than is necessary to wholly convert all the phosphoric acid to the soluble form, consequently more or less of all the forms of phosphoric acid are found to be present after the fertilizing materials have been treated or dissolved. Leibig, in 1840, was the first person to suggest the treatment of bones and mineral phosphates with sulphuric acid, for the purpose of rendering the phosphoric acid more available for plants. This may be said to be the beginning of the use of genuine artificial fertilizers. In the course of dissolving phosphates some of the phosphoric acid is set entirely free and

will be found as free phosphoric acid in freshly made goods, but this will remain so for only a comparatively short time. It will, in time, act on the insoluble phosphates contained in the fertilizer.

The water-soluble phosphoric acid is readily distributed in the soil, and is in a form that can be immediately absorbed by the roots and used by the plants as food, but, unfortunately, the water-soluble phosphoric acid will not remain long in the soil in this condition, for, coming in contact with the lime, magnesia, etc., in the soil, it reverts to a condition insoluble in water. In reverting, this water-soluble phosphoric acid is precipitated in such a way as to form a fine powder or coat over the particles of soil, and is thus in a finely divided state and presents a considerable surface which makes it easily dissolved by the acid soil waters, and the acid exudations of rootlets and thus still possesses a greater availability than any other form of phosphoric acid.

(2) REVERTED PHOSPHATE OF LIME.

Reverted phosphate of lime, also spoken of as "Reverted phosphoric acid," "Reverted calcium phosphate," "Precipitated phosphate of lime," "Citrate soluble phosphate," "Neutral phosphate of lime," and "Di-calcium phosphate," is quite insoluble in pure water, but is easily dissolved in water containing carbonic acid or salts of ammonia and in weak acids. The term reverted was originally intended to imply that this phosphoric acid had once been soluble, but for some cause had "gone back" to a form insoluble in water. This probably does take place to a limited extent, but as a matter of fact, in the course of manufacture, there is not sufficient acid used to make all the phosphoric acid soluble, and some of the tri-calcium phosphate loses only one part of lime, and thus leaves di-calcium phosphate remaining. As has been stated, some phosphoric acid is set entirely free, which will unite with insoluble phosphoric acid, and bring some of it to the so-called reverted form. This form of phosphoric acid is readily assimilated by plants, because the soil and solutions from the plant roots usually contain acids strong enough to dissolve it. Reverted phosphoric acid is, therefore, considered nearly as valuable as a plant food as the water-soluble form. Reverted phosphoric acid is often met with in small quantities in nature in connection with some insoluble phosphates, guanos, limes and other organic matter.

AVAILABLE PHOSPHORIC ACID.

In the commercial world and in stating the results of an analysis, the percentage of soluble phosphoric acid and the reverted or citrate soluble phosphoric acid are added together and the sum called *available phosphoric acid.*

(3) INSOLUBLE PHOSPHORIC ACID.

This is known under several names, as "Insoluble calcium phosphate," "Tri-calcium phosphate," "Bone phosphate of lime" and "Normal calcium phosphate." This form is called insoluble, because it does not dissolve in water or weak acids, as does the soluble or reverted phosphoric acid, but requires some strong acid to cause its decomposition or solution.

Insoluble phosphoric acid is found in nature in large quantities, some of the chief sources of which will be noticed later.

Insoluble phosphates are found everywhere in the soil and most of them are of but little value to the farmer, because they are not easily dissolved and can, therefore, be utilized but slowly by plants.

(4) TETRA-CALCIUM PHOSPHATES.

Tetra-calcium phosphate, or four-lime phosphate, is a form of phosphoric acid of recent discovery, and has been found to exist in slag phosphates. It contains more lime in proportion to phosphoric acid than any other form of phosphate. While it is insoluble in water, it has been found to be more available to plants than insoluble phosphate of lime (tri-calcium phosphate).

The following table gives the chemical composition and differences of the four phosphates of lime:

TABLE 5.

Chemical Composition of the Four Phosphates of Lime.

	Calcium—Per cent.	Phosphorus—Per cent.	Oxygen—Per cent.	Hydrogen—Per cent.
1. Soluble phosphate of lime,	17.1	26.5	54.7	1.7
2. Reverted phosphate of lime,	29.4	22.8	47.0	0.8
3. Insoluble phosphate of lime,	38.7	20.0	41.3	....
4. Tetra-calcium phosphate,	43.7	17.0	39.3	....

Or, taking it another way:

	Phosphoric acid P_2O_5 —Per cent.	Lime CaO—Per cent.	Water H_2O—Per cent.
1. Soluble phosphate of lime,	60.68	23.93	15.39
2. Reverted phosphate of lime,	52.20	41.18	6.62
3. Insoluble phosphate of lime,	45.81	54.19	....
4. Tetra-calcium phosphate,	38.79	61.21	....

TOTAL PHOSPHORIC ACID.

The total phosphoric acid is the sum of all the forms of phosphoric acid which a given fertilizer contains. In ordering dissolved rock, for instance, the total is equal to the soluble, reverted and insoluble phosphoric acid contained therein.

METHOD OF MANUFACTURING SOLUBLE PHOSPHATES.

The process of manufacturing soluble phosphates from bones or mineral phosphates is not very complicated, yet requires some chemical knowledge and experience, and facilities for carrying on the operation. The raw phosphates, whether of animal or mineral origin, are quite variable in their physical condition and chemical composition, yet the phosphoric acid will be found to be combined with lime, in the proportion of one part of the former to three of the latter, forming the tri-calcium phosphate.

The chief result which the manufacturer desires to arrive at is to make the tri-calcium phosphate soluble in water or in neutral ammonia citrate. To do this the chemist has worked upon the following basis: Sulphuric acid is known to be more energetic in its action at ordinary temperature than any other acid used in industry. It, therefore, has the power of displacing all other acids from their salts and of taking their bases to itself to form sulphates, which, for the most part, are quite staple and easily handled substances. The acids which are chiefly present in natural phosphates are phosphoric, carbonic, fluoric and silicic. These, when brought in contact with dilute sulphuric acid, are all displaced, and the bases become sulphates. Chemists have determined how much sulphuric acid is required to displace each of the various acids present, and to form sulphates with the bases with which they are combined, so that, after the composition of a natural mineral phosphate has been determined, the amount of sulphuric acid of a given strength which

it is necessary to use in order to bring the desired change of a tri-calcium phosphate to the soluble and reverted forms, can be easily calculated. These amounts have been worked out for practice as expressed in the following table:

TABLE 6.*

One Part by Weight of Each Substance Below Requires, Sulphuric Acid by Same Unite of Weight.

	At 48° B.	At 50° B.	At 52° B.	At 54° B.	At 55° B.
Tri-calcium phosphate,	1.590	1.517	1.446	1.382	1.352
Iron phosphate,	1.630	1.558	1.485	1.420	1.390
Aluminum phosphate,	2.025	1.930	1.839	1.756	1.721
Calcium carbonate,	1.640	1.565	1.495	1.428	1.411
Calcium fluoride,	2.060	2.010	1.916	1.830	1.794
Magnesium carbonate,	1.940	1.860	1.775	1.690	1.660

*H. W. Wiley's "Principles and Practice of Agricultural Analysis," Vol. II, pp. 155.

Example.—Suppose, for example, a phosphate of the following composition, is to be treated with sulphuric acid, viz:

	Per cent.
Moisture and organic,	4.00
Calcium phosphate,	55.00
Calcium carbonate,	3.00
Iron and aluminum phosphate, nearly all A.,	6.50
Magnesium carbonate,	0.75
Calcium fluoride,	2.25
Insoluble,	28.00

Using sulphuric acid of 50° B., the following quantities will be required for 100 kilograms:

	Kilos* of acid required.
Calcium phosphate, fifty-five kilos,	83.44
Calcium carbonate, three and a half kilos,	5.48
Calcium fluoride ,two and a quarter kilos,	4.52
Aluminum and iron phosphate, six and a half kilos,	12.55
Magnesium carbonate, three-quarters of a kilo,	1.40
Total,	107.39

*One kilo—about 2.2 lbs.

The material, before treatment, is always finely ground so as to facilitate the chemical action. After the treatment has been completed the mass is dried and ground for use.

The materials which are chiefly used as sources of phosphoric acid in fertilizer are given in the following table, together with their average composition :

TABLE 7.

Giving the Approximate Amount of Phosphoric Acid in Fertilizing Materials.

Materials Containing Phosphoric Acid.	Phosphoric acid (P_2O_5). Soluble—Per cent.	Reverted—Per cent.	Insoluble—Per cent.	Total—Per cent.	Lbs. in one ton. Available phosphoric acid.	Total phosphoric acid.
Apatite,	......	......	......	38.0	......	760
Bone ash,	......	......	......	35.9	......	718
Bone black,	......	......	......	28.3	......	567
Bone black (dissolved),	16.0	0.7	0.3	17.0	334	340
Bone meal,	0.4	6.5	15.6	22.5	138	450
Bone meal (from glue factory),	......	6.5	22.4	28.9	130	578
Bone meal (dissolved),	10.0	5.0	2.5	17.5	300	350
Carribean guano,	......	......	......	18.9	......	378
Cuban guano,	......	......	......	17.9	......	358
Double super-phosphate,	......	......	4.0	44.0	800	880
Florida rock,	......	......	......	30.0	......	600
Florida soft phosphate,	......	......	......	24.0	......	480
Keystone concentrated phosphate,	0.3	38.2	9.2	47.7	770	950
Mona Island phosphate,	......	7.5	14.3	21.8	150	436
Navassa phosphate,	......	......	......	34.3	......	686
Orchilla guano,	......	......	......	26.8	......	536
Peruvian guano,	4.6	3.8	4.9	13.3	168	266
South Carolina rock (ground),	......	0.3	27.7	28.0	6	560
South Carolina rock (floats),	......	0.5	27.5	28.0	10	560
South Carolina rock (dissolved),	10.5	3.5	2.0	16.0	280	320
Slag phosphate (American),	......	......	......	21.0	......	420
Slag phosphate (German),	......	......	......	30.0	......	600
Tennessee phosphate rock,	......	......	......	35.0	......	700

SOURCES OF SUPPLY OF PHOSPHORIC ACID.

A study of the figures given in the preceding tables, particularly those of Table 4, leave but little doubt but that there must come a time with all soils, under normal conditions of cropping, when their natural contents of phosphoric acid will be much reduced, if not exhausted. This has been the experience of farmers the world over. Happily, nature made ample provisions for supplying all requirements for this valuable and essential plant food.

The first material used for furnishing phosphoric acid was bone, and the chief reliance was placed in this source for many years and even now it is very popular and furnishes a considerable percentage

of the amount used. But very soon it was determined that phosphoric acid was the chiefly valuable ingredient in bone and that phosphates were so essential for plant growth and development, it was pointed out by Professor Henslow, in 1845, in a lecture before the British Association, describing the Suffolk Coprolites, that these deposits of mineral phosphates could be of immense value for application in agriculture.

Even at this time large workable deposits of mineral phosphates were known to exist, they having been almost simultaneously discovered in several countries, notably those discovered by Buckland, in England, Berthier in France and Holmes in America (Ashley River, S. C., 1837), and since that time numerous other large deposits have been discovered in almost every part of the world, but those which are of special interest in the United States are those deposits of Florida, Tennessee and Virginia.

The mode of occurrence of the best-known deposits of phosphates of lime are quite erratic. They have been found in rocks of all ages and of nearly every texture. Sometimes they are very pure, sometimes their constituents are extremely variable. Sometimes they are found in veins, sometimes in pockets and again in stratified layers or beds, in connection with fossilized remains of all kinds deposited by ancient seas.

The supply of phosphates available for agricultural purposes may be divided, from a chemical standpoint, into two principal classes:

1st. Phosphates of lime or calcium phosphates.

2d. Phosphates of iron and alumina.

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(1) PHOSPHATES OF LIME OR CALCIUM PHOSPHATES.

For the manufacture of fertilizers and for agriculture purposes, phosphates of lime are generally preferred. This preference by the manufacturer is due to the physical characteristics of the compounds formed when treated with acid, and the preference on the part of the farmer no doubt has been moulded in a measure by the preferences of the manufacturers, yet, to a large extent, is probably due to the fact that bones are phosphates of lime, and they learned early to appreciate the good effects of bone and also in many sections recognized the great value of lime as a soil improver.

In this connection, there has been given a detailed description of the various sources of lime phosphates, and for their chemical distinctions, see under "Forms of Phosphoric Acid," on page 18.

SOUTH CAROLINA PHOSPHATES.

For the eastern farmer, the deposits of phosphates in South Carolina are by far the most interesting of any in the world, for they have done much towards increasing the productive capacity of many soils, and have made it possible to profitably farm very considerable areas that otherwise would have been abandoned. Their discovery has also, in a measure, revolutionized the agricultural pursuits of all parts of the world. The discovery of the deposits of phosphates in South Carolina is generally attributed to Prof. Francis S. Holmes, and probably rightly so, for it certainly was in connection with his work that the true character of these deposits were disclosed. Some make claims of the discovery for Dr. N. A. Pratt, and there is no doubt but that his work contributed toward demonstrating for the first time the true richness and value of the deposits. However, the existence of the deposits were known even before the date of Holmes' explorations, as is evidenced by the reference made to them as early as 1802 by Judge John Draton, but their practical value was not suspected. At that period marl or carbonate of lime was the valuable product, and these deposits were referred to by Mr. Ruffin, the State Geologist, as the "great Carolinian marl beds." Again, the attention of the people of Charleston was called to the fossil remains in that section, and to their similarity to the Coprolite deposits of England by the writings of an English tourist about 1820.

As these deposits have played so important a part in the agriculture of the Eastern States during the past thirty-five years, it may be interesting and not out of place to give a short sketch of the incidents relating to the discovery and the development of the deposits.

On the discovery of the deposits, Prof. Holmes, in "Phosphate Rocks of South Carolina," says:

"Some time in November, 1837, in an old rice field about a mile from the west bank of the Ashley river, in St. Andrew's parish, we found a number of rolled or water-worn nodules of a rocky material filled with the impression of marine shells. These nodules, or rocks, were scattered over the surface of the land, and in some places had been gathered into heaps, so that they could not materially interfere with the cultivation of the field. As these rocks contained little carbonate of lime (the material of all others then most eagerly sought after), the nodules were thrown aside and considered useless as a fertilizing substance. In a low part of an old field (Dec. 9, 1843), we attempted to bore with an augur below the surface to ascertain the nature of the earth beneath, with the hope of finding marl. On removing the soil above the rocks, they were seen in regu-

lar stratum about one foot thick, embedded in clay, and seemed to be identically the same as those found scattered on the surface of an adjoining field, all of them bearing impressions of shells, and having similar cavities and holes filled with clay. It was on the 23d or 24th of February, 1844, whilst engaged in the removal of the upper beds covering the marl, that the laborers discovered several stone arrow heads and one stone hatchet. Not long after finding these relics of human workmanship, and while engaged in our usual visits to the Ashley bed (marl), a bone was found projecting from the bluff immediately in contact with the surface of the stony stratum (the phosphate rock); we pulled it out, and, behold, a human bone! Without hesitation, it was condemned as an 'accidental occupant' of quarters to which it had no right, geologically, and so we threw it into the river. A year after, a lower jawbone, with teeth, was taken from the same bed. Subsequent events and discoveries show conclusively that the first described bone was 'in place,' and that the beds of the Post-Pliocene, not only on the Ashley, but in France, Switzerland and other European countries, contain bones associated with the remains of extinct animals and relics of human workmanship, proving most conclusively that the Carolina specimens were found in place, and as the European discoveries were made in 1854, and ours in 1844, to South Carolina should be awarded the honor of the first discovery.

"Whilst engaged in manufacturing saltpetre, on the west bank of the river, during the Confederate war, the lime or calcareous earth necessary in such operations was obtained by sinking pits into the Eocene marl bed. Upon the removal of a few feet of the upper layers the workmen discovered in one pit a number of oddly-shaped nodules, resembling somewhat the marl stones (phosphate rock) found in the stratum above the marl, but more cylindrical in form and not perforated, and having their exterior polished, as though each individual specimen had received a coat of varnish. They appeared to have been deposited in a large corner or pocket in the marl bed. These specimens were preserved and subsequently submitted to analytical tests, when their true value was revealed, and then began the practical work that demonstrated the fact that South Carolina possessed a deposit of phosphates the richest, perhaps, in the world."

So much for the discovery of the South Carolina phosphates. The commercial history and benefits flowing therefrom are full of interest to both business man and farmer.

On the development of the deposits, L. A. Ransom has given the following brief summary in the "Manufacturers' Record:"

"The beginning of the War of 1861 interrupted the investigations, then in progress by Mr. Ruffin, Professors Holmes and Pratt, Dr.

Shepard, Dr. St. Julien Ravenel and other scientific men. It was not until 1867, when reaction from the effects of the war began to set in, that attention was then directed toward the development of these deposits. In 1867, the Charleston, South Carolina, Mining and Manufacturing Company was organized to work the land deposits. A few Charleston and Philadelphia capitalists furnished the funds and Professor Holmes was elected President. The principal office was in Charleston, but a branch agency was established in Philadelphia. In 1870, the capital of the company was $800,000, and is at present $1,000,000. Many difficulties were met and overcome in this work, and much money was sunk, because the field of work was a new and untried one, and experience had to be gained by great loss of time and a large expenditure. In 1867, sixteen barrels of the rock were shipped to Philadelphia by Prof. Holmes for general distribution, and the first parcel of super-phosphates (commercial fertilizers) was manufactured by Messrs. Potts & Klett, of that city. The first cargo of 100 tons was shipped on the 14th of April, 1868, to Baltimore, Md., by John R. Dukes, president of the Wando Co., of Charleston." Prof. Holmes thus describes the reception of the rock in the markets: "The arrival of the first cargo in Philadelphia caused no little excitement in mercantile circles, especially among the manufacturers of fashionable fertilizers, and in a very short time after the chemists of that city, New York and Baltimore had pronounced it a true bone phosphate rock, the phosphate fever became epidemic in these cities."

The organization of companies to mine the river deposits followed close upon that of the land companies, the Marine and Oak Point mines being the pioneers. With the beginning of river mining, in 1870, the State, through the legislature, claimed control of the navigable streams, and by act of the assembly, imposed a royalty of $1.00 per ton on all rock removed from these streams. A charter was granted to the Marine and River Company, which gave it the exclusive rights to all the streams of the State upon the filing of a $50,000 bond and the punctual payment of royalty, quarterly. In 1870, three years after the commencement of mining operations, there were at work two river companies, five land companies and six companies manufacturing the rock into commercial fertilizers. The Marine and River Company leased a part of their territory to the Coosaw Mining Company, an organization composed of Baltimoreans and Charlestonians, and organized in May, 1870. This has been the most successful of all the river mining companies, because the most persistent. At the end of the first year's experience it had expended all its money and had nothing left except a dredge and some experience. Many of the parties interested favored suspend-

ing work, but largely through the influence of Mr. Robert Adger, the chief manager, operations were continued, additional capital raised and the result was the remarkable financial success already mentioned. Subsequent to the organization of the Coosaw Company, the Marine and River Company failing to comply with the terms of its grant from the State, forfeited its charter and retired from business, because they had found mining unprofitable. The Coosaw entered into new conditions and bonds directly with the State for the territory it had previously worked under permits from the Marine and River Company, in 1876, and continued work. After overcoming apparently insurmountable difficulties, employing the best talent for mining and marketing its product, it has rewarded its projectors, and paid handsome dividends to its stockholders.

The phosphate deposits in South Carolina are designated under the heads, viz: as "Land rock" and "River rock," according to the location in which it is found. These two classes vary some in physical characteristics, but not greatly in chemical composition.

The most prominent characteristic of the native Carolina phosphate is its nodular form. Even where the deposits occur as an apparently smooth and compact layer, or in large, flat cakes, it is, nevertheless, composed of irregular nodules, partially cemented or compacted together. Nearly all these nodules have the egg or kidney shape. The exterior is sometimes rough and indented, often honeycombed with irregular holes, and sometimes it is smooth and compact. The surface is occasionally shiney and coated, as if with enamel. Fossil shells, fish bones and teeth are not infrequently found imbedded in the nodules, and other animal remains occur in the same general deposits. The nodules vary in size from the fraction of an inch to several feet in diameter, and weigh from almost a ton downwards. When found, as much of this deposit is, in river bottoms or under marsh mud, the color of the material is a gray or bluish black. The land rock is usually of a lighter color, yellowish or grayish white. The masses are easily broken and ground to a fine powder, light yellow or gray, often becoming so fine as to float in the air. In this extremely fine condition, and before being treated with acid, the material is often called *Floats*. There is no reasonable doubt that these phosphates came from the remains of both marine and land animals, although it would be out of place to give the evidence here. A long series of geological transformations is involved, together with different eras of animal life, and subsequent changes in the mineral matters themselves. From several hundred analyses of the raw or simply ground Carolina rock, the mineral has been found to contain on an average from 25 to 28 per cent. of phosphoric acid—2.5 to 5 per cent. carbonic

acid, 0.5 to 2 per cent. sulphate acid, 35 to 42 per cent. lime and a little magnesia, soda, silica, iron and other elements. The finding of the fossil bones, teeth, etc., spoken of has led to the term "South Carolina bone," being incorrectly applied to these mineral phosphates.

DISSOLVED SOUTH CAROLINA ROCK.

Rock which has been treated with sulphuric acid to render the phosphoric acid soluble or available is termed Dissolved South Carolina rock. This constitutes by far the greater bulk of the materials now used in this country for making phosphate manures. An immense trade has grown up in this class of phosphates during the last thirty-five years. The most common name by which this class is known is "Acid Phosphate," but it is also found on the market as Dissolved S. C. Rock, Dissolved S. C. Bone and Bone Phosphate Rock. While the rock which was first used for making this class of fertilizers was first found in South Carolina, yet much of it now comes from Florida and Tennessee. The dissolved phosphates of this class contain a large portion of their phosphoric acid in the available condition, but not quite as much in the soluble form as in dissolved bone black.

DOUBLE SUPER-PHOSPHATE.

This, as its name indicates, is a concentrated form of soluble phosphoric acid. It is made by dissolving mineral phosphates in phosphoric acid instead of sulphuric acid. The process of manufacture consists of treating a low grade of phosphate rock, or those too poor in phosphoric acid to make a high grade or standard super-phosphate, with an excess of dilute sulphuric acid. This sets free the phosphoric acid, which, together with the excess of sulphuric acid, is removed and separated from the insoluble materials by filtration and washing. The acid solutions thus obtained are concentrated and then used for dissolving the better class of phosphate rock. Because the acids used for dissolving the phosphates contain phosphoric acid, the product yielded contains more than double the amount of phosphoric acid in the ordinary product.

Double super-phosphate is manufactured to some extent in this country, but mostly in Europe. Its use in this country is not as great now as it was a few years ago. This was selected as one of the sources of phosphoric acid, as it contains a minimum of impurities and a maximum of phosphoric acid in the soluble form.

SUPER-PHOSPHATE.

This was the name originally given to a fertilizer which had been treated with acid to render the phosphoric acid soluble, but in after

years it came to be commonly applied to all classes of fertilizers rather indiscriminately, especially to all those which had a dissolved bone or rock as a base, even if some nitrogen or potash had been mixed with it. To overcome this difficulty the term "Plain Super-phosphate" came into existence to designate a dissolved phosphate which contained only phosphoric acid.

FLORIDA PHOSPHATES.

These phosphate deposits are of two general classes, viz: The phosphates of lime and the phosphates of iron and alumina.

The Florida deposits, perhaps, have more commercial interest at this time than those of South Carolina, as a large part of all the rock fertilizers on the market are manufactured from the Florida goods. There is very little difference in general composition and characteristics between the deposits of these two States, except that perhaps more of that from Florida runs smaller in size, so that it is popularly designated "Pebble Phosphates." There are both river and land deposits of these pebble phosphates, as well as the land rock phosphates. Florida phosphates were discovered in the winter of 1881 by Francis LeBaron, a member of the United States Army Engineer Corps, while surveying a canal route from the headwaters of the St. John river, in South Florida, to Charlotte Harbor. Mr. LeBaron did not make the discovery public, but recognized the importance and value of the "find," and confided the matter as a secret to a few wealthy gentlemen. These capitalists were timid, if not skeptical, and so did nothing. The public was not apprised of the existence of the phosphate deposits until 1888, and even then it excited but little interest, for it was thought that the deposits were small and confined to a limited area.

In 1888, Mr. T. S. Moorehead, of Pennsylvania, followed up the discovery of LeBaron—information of which he had obtained in some way—and acquired possession of some of the richest of the Peace river deposits and started mining in a small way. He made the first shipment of phosphates that ever went out of Florida in May, 1888, and the total shipment for that year was only 2,000 tons.

It is interesting to note that with the Florida deposits, as with those of South Carolina, the first capital for the development was ventured by people from Pennsylvania.

TENNESSEE PHOSPHATES.

The deposits of phosphates in Tennessee, from a commercial and agricultural standpoint, to-day are next in importance to those of the two States mentioned above. The deposits in Tennessee were discovered in 1894, and they have been extensively explored and

rapidly developed since that time. These deposits differ from those of South Carolina and Florida in that it does not exist as pebbly nodules or bowlders, but in veins and pockets. The deposits vary in composition, yet many of the veins are very rich and relatively pure phosphate of lime. This makes them a valuable source of supply for the manufacturer.

PENNSYLVANIA PHOSPHATES.

The deposits of phosphates in Pennsylvania, as far as known at the present time, are not very extensive, yet they give promise of assuming some importance. Mr. T. S. Moorhead, of Port Royal, president of the Tuscarora Valley Railroad, was probably the first to call public attention to the existence of phosphate rock in Pennsylvania, in 1895. He sent numerous specimens of these deposits to the Pennsylvania Experiment Station for examination, and a detailed report of as much as was known of the extent and character of the deposits up to that time was made in 1896, in Bulletin No. 34, of that Station.

Three classes of phosphates have thus far been discovered. The first, a friable white rock, locally known as "white vein," and contains from 29 to 54 per cent. of bone phosphate. The second consists of red nodules and contains considerable iron and alumina and an equivalent of from 45 to 52 per cent. of bone phosphate. The third occurs in blocks which resemble blue limestone, and contains about 40 per cent. bone phosphate of lime. Eight feet is the thickest vein discovered as far as reported.

While these materials are of much lower grade than the phosphates of South Carolina, Florida and Tennessee, yet it is of considerable importance, locally, and will be valuable for shipment to nearby points.

Some idea of the amount of phosphate rock consumed annually, can be gained from the following figures, which give the amounts mined in the different States during the year 1900:

Region.	Long Tons.
Florida,	582,900
Tennessee,	436,000
South Carolina,	562,000
North Carolina,	15,250
Pennsylvania,	3,750
Total,	1,599,900

VIRGINIA PHOSPHATES.

The Virginia deposits are attracting more or less attention at this time, but they have not been extensively developed. They are not unlike those of South Carolina in general composition, though they contain rather more iron and less phosphoric acid.

APATITE.

Apatite is the name given to a mineral phosphate of lime found in numerous localities. It occurs in the State of New York and in very large masses in different parts of Canada. But, as usually found, it is exceedingly hard and difficult to grind, besides being badly mixed with other and worthless minerals. These objections have prevented apatite from being extensively used in the manufacture of fertilizers, although it is rich in phosphoric acid, sometimes containing as much as 40 per cent.

CAPROLITES.

Caprolites, or coprolites, resemble, in most respects, the nodules of the American phosphate deposits, but average smaller and more even in size, ranging from one to four inches in diameter. They are not common to this country, but are found in England and France in quantity and are there used for making commercial fertilizers by the thousands of tons. They are believed to be the dung of extinct animals, changed into a mineral form and worn by water into their usual kidney shape. They also contain other animal remains, such as teeth, scales and fish bones. They show, by analysis, 25 to 30 per cent. of phosphoric acid.

PHOSPHORITES.

Phosphorites are another form of mineral phosphates closely allied to apatites, and found in France, Germany and Spain, where they are of commercial importance as fertilizer material.

There are extensive deposits of phosphatic substances in England, France, Belguim and Russia, not especially described, because having little effect upon the supplies of phosphates for America.

SLAG PHOSPHATE.

Slag phosphate, *Basic iron slag or Thomas slag-meal*—to these names may be added *Thomas Scoria* and *Odorless phosphate*, all given to a waste material or slag, which is a by-product in the preparation of steel, by what is known as the "basic process." The object of this process is the extraction of phosphorus from pig iron, by means of a basic lining of the converter invented by Jacob Reese. The

product of the process is a substance containing 15 to 20 per cent. of phosphoric acid. It is metallic in appearance, but may be ground, forming a dark brown meal. The phosphoric acid is in combination chiefly with lime, as tetra-calcium phosphate; it is insoluble in water, slightly soluble in ammonium citrate, and is, by ordinary methods of analysis, classified largely as insoluble. Yet its condition is such that soil water, when charged with carbonic acid, will dissolve it to a considerable degree. Thomas slag is largely used and highly valued in Germany, and is the cheapest form in which phosphoric acid can be obtained by the farmers of that country. Wagner states that two compounds of this material, ground fine (but no acid treatment), containing 18 per cent. phosphoric acid and no other valuable plant food, and costing four and one-half cents, produces the first year after its use, the same increase in yield as one pound of soluble phosphoric acid from bone meal costing six and one-half cents. And in the second year the effect of the Thomas slag was twice that of the other. These are important facts, but the place of this slag phosphate among the commercial fertilizers of this country has yet to be determined.

This material gets the name, by which it is best known in Europe, from S. G. Thomas, of England, who claimed to be the prior inventor of the basic process of making pure steel. This claim was disputed by Jacob Reese, of Pennsylvania, and the courts of this country have confirmed the claim of Reese. The slag is now manufactured by the latter in large quantities at Pottstown, Pa., and is sold under the name of Odorless Phosphate. This is the slag very finely pulverized, but not treated with acid. An idea of the growth of the consumption of slag phosphate may be gotten from the following report, showing its production:

TABLE 8.

Slag Phosphate Produced.

Year.	Tons.
1878	4
1879	360
1880	15,000
1881	100,000
1882	135,000
1883	190,411
1884	259,000
1885	283,495
1886	412,505
1887	511,344
1888	585,970
1889	682,365
1890	783,924
1891	720,134
1892	800,660
1893	874,000
1894	896,301
1895	934,235
1896	962,050
1897	1,033,002
1898	1,105,000
1899	1,250,120
1900	1,462,325
1901	1,700,000

BASIC SUPER-PHOSPHATE.

This is a class of super-phosphate that was introduced in the English market in 1900. It is made up of a mixture of slaked lime and ordinary super-phosphate. The idea that led up to the making of this mixture was caused by an effort to produce an alkaline phosphate with some of the characteristics of slag phosphate, but one which would also give results on sandy and other soils that were deficient in organic matter. This basic super-phosphate can also be used on soils which are acid and upon which ordinary super-phosphate (acid phosphate) gives poor results. In fact, the claim is made for it that it possesses all the advantages of both slag phosphate and of acid phosphate.

The following laboratory experiments* show the relative solubility of basic slag phosphate and the basic super-phosphate:

*Experiments of John Hughes, originator of the basic super-phosphate.

Solubility in Cold Water After 48 Hours. (1 part phosphate to 1,000 parts cold water.)	Basic super-phosphate.	Basic slag.
Portion soluble in cold water,*	66.80	6.60
Portion insoluble after ignition,	33.20	93.40
	100.00	100.00
Containing:*		
Soluble lime,	22.28	4.70
Phosphate of lime,	None.	None.

These figures show the basic super-phosphate to have ten times as much matter soluble in pure cold water as the slag phosphate, and may indicate the reason for slag phosphate not acting on soils which are lacking in vegetable matter. Nevertheless, it will be noted that there was no phosphate dissolved by the water from either substance.

The solubility in weak acid solution was as follows:

Solubility in (1 in 1,000) Citric Acid Solution After 24 Hours. (1 part in phosphate to 1,000 parts solution.)	Basic super-phosphate.	Basic slag.
Portion soluble in citric solution,*	94.20	38.80
Portion insoluble after ignition,	5.80	61.20
	100.00	100.00
Containing*		
Soluble lime,	34.73	22.17
Soluble phosphoric acid,	12.45	8.70
Equal to phosphate of lime,	27.18	18.99

Basic super-phosphate is probably made by mixing one part of finely ground or slaked lime with three parts of plain super-phosphate or dissolved or acid phosphate.

Basic super-phosphate is not unlike, in some respects, to the non-acid phosphate which was manufactured in Baltimore a few years ago under the Hoskin patents.

RAW BONE, GROUND BONE OR BONE MEAL AND DISSOLVED BONE.

Animal bones are composed of two distinct substances, which interpenetrate one another. There is a sort of frame-work of earthy matter, which is a substance containing much nitrogen. Raw bones are, therefore, doubly valuable for manurial purposes, because they contain both phosphoric acid and nitrogen. As ordinarily collected, bones contain from 50 to 60 per cent. of phosphate of lime and from 5 to 7 per cent. of nitrogen. Fresh raw bones also contain fat, and this is not only useless as a plant food, but it adds weight to the bone and makes it hard to grind, and, when ground, the more fat remaining in the bone the slower will be the decomposition in the soil. To obviate this difficulty, bones are generally steamed, or carried through some process to remove the fat, before they are ground for fertilizers. Steamed or dessicated bones, if not too strongly steamed, are better for fertilizer than raw bones. Some nitrogen is lost by this process, but if carefully done, the gain exceeds the loss. Bone meal is obtained by grinding the crude or steamed bones, and it is valuable in proportion to the degree of fineness to which it is reduced. According to its fineness, it is variously called ground bone, bone meal, flour of bone and bone dust. The finer it is, if used without acid, the easier it decays or dissolves in the soil, and the sooner the chemistry of nature converts the (tri-calcic) phosphate of lime to a form available to plants. Good ground bone or bone meal should contain from 20 to 25 per cent. of phosphoric acid and from 3 to 4 per cent. of nitrogen.

The demand for bones for use in various arts and especially in refining sugar, is making this form of fertilizing material comparatively scarce in the market and correspondingly high in price. If rates advance much, it will become unprofitable for farmers to use bone fertilizers for their phosphates. The same causes lead to the considerable adulteration of bone meal that is now found. Lime, gypsum, coal ashes, ground oyster shells, crab shells and like articles are used for this purpose as well as the less objectionable mixing of fine-ground rock phosphate, all being sold under the name of bone. When bone, ground bone or bone meal is treated with sulphuric acid, the product is the dissolved bone of our markets, also known as acidulated bone, soluble bone and dissolved bone phosphate. This is simply an acid phosphate or super-phosphate, made from bones.

BONE BLACK AND DISSOLVED BONE BLACK.

When broken bones are placed in a retort or iron cylinder, the air being excluded, and then strongly heated, gas, water, oily matters and other products are driven off, while black bone charcoal is left.

This product, also known as bone black and animal charcoal, is used extensively in sugar refineries for taking the coloring matter out of raw sugars. From time to time portions of the bone charcoal cease to be effective in clarifying and the spent black is then sold by the refineries for fertilizing purposes. All the phosphoric acid originally in the bones is retained, but the presence of carbon prevents the phosphate from decomposing. It is as "dissolved bone black" that this article is generally found on the market. Dissolved bone black contains a large proportion of soluble phosphoric acid and a very small amount in the insoluble form.

BONE ASH.

The supply of bone ash comes mainly from South Africa, where the bones of animals are used as fuel in extracting the fats from the carcass. In the process of burning, all the organic matter is destroyed, so that the nitrogen of the bones is lost. Bone ash contains from 30 to 35 per cent. phosphoric acid, and in a form so insoluble that this material is little used as a fertilizer until it has been treated with acid.

At one time this source supplied considerable phosphoric acid and was found on all markets, but at the present time little or none is to be found.

PRECIPITATED BONE OR PRECIPITATED PHOSPHATE.

Every year large quantities of bones are treated with hydrochloric (muriatic) acid for the purpose of dissolving the mineral matters of the bone and of obtaining their ossein for use in the manufacture of gelatine. To the clear solution of phosphate of lime in hydrochloric acid thus obtained is added enough milk of lime to neutralize the acid and precipitate the phosphate. The precipitate is in the form of a very fine powder and may be used directly for fertilizing purposes, or it is sometimes treated with sulphuric acid to render the phosphates soluble as, precipitated, this material contains, on the average, about 18 or 19 per cent. of phosphoric acid.

There is also some precipitated phosphates that come from other manufacturing sources.

BONE TANKAGE.

Tankage is the residue remaining in the tanks used for boiling cattle heads, feet and all sorts of slaughter house refuse.

Bone tankage represents an important source of phosphoric acid. It is so closely related to raw bone or steamed bone as far as its contents of phosphoric acid are concerned that it is not necessary to say more here on that point. Tankage is also quite available as a source of nitrogen or ammonia in making mixed fertilizers. There

are six grades of bone tankage recognized in the trade: 1st grade, containing 18 or 19 per cent. of phosphoric acid; 2d grade, 16 per cent. phosphoric acid; 3d grade, $13\frac{1}{2}$ per cent. phosphoric acid; 4th grade, $11\frac{1}{2}$ per cent. phosphoric acid; 5th grade, 9 per cent. phosphoric acid, and 6th grade, 7 per cent. phosphoric acid. The nitrogen of tankage increases as the percentage of phosphoric acid decreases.

OTHER ORGANIC SOURCES OF PHOSPHORIC ACID.

There are numerous other sources of phosphoric acid which may all be included in the class of refuse or by-product materials. Dried fish, which contains about 7 or 8 per cent. of phosphoric acid, is the most important of this class. Cotton seed meal and castor pomace are also important sources of phosphoric acid.

PHOSPHATIC GUANO.

There are two classes of phosphatic guanos; those which are largely lime phosphates and another class which are largely iron and alumina phosphates. Both these classes are called guanos because they resemble one another very closely in general appearance, and were probably of the same origin. These guanos were formed from the dung of birds. The Peruvian guano was the first to come into general use and it gave remarkably good results, but it contained some nitrogen and potash, as well as phosphoric acid. The other phosphates of this class, while resembling the Peruvian guano much in appearance, yet were formed in rainy regions, which washed out the nitrogen and potash of the original dung. The following are the principal phosphate of lime guanos: Baker Island guano, which contains 65 to 85 per cent. of lime; Howlands Island and Jarvis Island are both nearly as good. These three islands are in the Pacific ocean. Majellones and Patagonia phosphates are both rich in phosphate of lime, and also contain some nitrogen. The Mona Island, Navarsa and Orchilla guanos contain considerable phosphate of lime, but also have a marked per cent. of iron and alumina phosphates, which places them in the latter class as far as their value for manufacturing purposes is concerned.

IRON AND ALUMINA PHOSPHATES.

Very large deposits of phosphates of iron and alumina have been discovered in many places of the West India Islands. They were at first mistaken and shipped in large quantities for phosphate of lime. Upon complete analysis their true nature was determined, and because they were unsuitable for the manufacture of super-phosphates, giving, when treated with sulphuric acid, a sticky mass

which was hard to handle, to dry and prepare in a good mechanical condition, they were denounced by many chemists as valueless for fertilizing purposes.

The chemists, in stating that this class of phosphates was valueless for fertilizing purposes, evidently went a step too far, for they should have said that they were not suitable for the manufacture of super-phosphates: It is a notable fact, which some chemists evidently overlooked, that the phosphoric acid which is found naturally in the soil exists largely in the form of iron and alumina phosphates.

While this class of phosphates are not adapted for making superphosphates and, consequently, are unpopular with the manufacturer of chemical fertilizers, yet it must be admitted, in the light of results of numerous experiments, that they are valuable in the raw state, if fairly pulverized, as a direct fertilizer.

The following analysis gives a fair idea of the composition of this class of phosphates:

	Per cent.
Moisture,	12.36
Water of combination,	4.13
Phosphoric acid,*	30.22
Lime,	4.16
Magnesia,	Trace.
Oxide of iron,	7.04
Alumina,	24.00
Carbonic acid,	None.
Sulphuric acid,	None.
Fluorine,	Trace.
Insoluble matter, sand, etc.,	18.09
	100.00

*Equal to 65.87 per cent. of tri-basic phosphate of lime.

FLORIDA SOFT PHOSPHATES.

This is probably the most important alumina and iron phosphate to the States of the Atlantic ocean border at the present day, both from an agricultural and commercial standpoint. There is considerable deposits of this class of rock in Florida. It is known as soft phosphate because of the ease with which it is broken up and pulverized. As has been said, it is not well adapted for treatment with acid for making soluble phosphates, as the alumina and iron make a sticky mass which is hard to dry and keep in a good mechanical condition. Hence, it has not been mined extensively or had a large sale. Locally, this soft phosphate has had extensive use in its natural condition. Its application has given good results on sandy land, which had been given heavy dressings of the native

swamp and lake muck. This muck furnishes nitrogen as well as the much-needed organic matter. These phosphates have also given good results on the "hammock lands."

ALUMINA AND IRON PHOSPHATE GUANOS.

As has been already mentioned, there is a large class of phosphates which are derived from the dung of birds and sea fowls, which go under the term of guano. These phosphates have more the appearance of earth than of organic products. As originally formed, of course, these were mostly phosphates of lime, but through the action of the water, in conjunction with the rock and soil characteristics of the islands, the lime has been replaced by alumina and iron. Most of the phosphates from the islands off the coast of South America and from the West India and Caribbean Islands belong to the alumina and iron class.

They are popularly known under the name of the island on which they are found, and the principal ones which are met with in agricultural literature and trade are as follows: Alta Vela, Caribbean, Cuban and Redunda phosphates or guanos, besides the Mona Island, Navassa and Orchilla guanos already mentioned.

THE USE OF PHOSPHATES.

There seems to be but little doubt as to the need for the application of phosphates when the amount that is being taken out of the soil annually by crops is considered. It has been seen from the matter on the preceding pages that there is an abundant supply of phosphoric acid to draw from, and in quite a variety of forms, so that it would seem possible to be able to comply in this respect with almost every requirement of the soils and crops which might be presented. While most farmers seem to be aware that there is a variety of sources of phosphates, yet they have not come to give that consideration to the other phases of the subject as would seem desirable in order that the different phosphates might be used most intelligently or with more profit. In this connection, the following questions immediately arise in the minds of the farmer:

1st. Under what conditions is it possible to essentially increase the returns from the soil by the application of phosphates?

2d. What kind of phosphates shall be used?

3d. How shall it be used or applied?

4th. How much shall be used?

These are all natural questions and ones to which every farmer could well give more study. The first point to study in the consideration of the question of the application of phosphates is the

same that arises in connection with the use of any fertilizer, and that is as to the consideration of the particular soil in question and its requirements.

The cause for small returns from land is not always a lack of plant food, consequently this is the first point to be considered. Often the plant suffers from either one or a combination of the following troubles:

1st. Gets thirsty from an insufficient supply of water.

2d. The soil is not properly aerated.

3d. From an insufficient porosity of the soil, whereby root development is checked.

4th. From caking of the soil, which works harmfully and locks up plant food.

5th. From the soil being impenetrable, which makes the soil wet, with all of its attendant evils.

6th. From lack of humus or organic matter and, hence, the soil is heavy and lifeless.

7th. From the soil being acid, which prevents normal plant development and especially the growth of the beneficial micro-organisms of the soil.

8th. Occasionally in the east, and often in the west, the soil is overcharged with soluble salts, which prove harmful.

In short, there are many physical and chemical relations of the soil or unfavorable conditions of the health of the plant which exert an injurious influence on the proper development of the plant, and, hence, cut down the yield.

In such cases, the plant seldom has need of a large addition of food, and the first step toward an improved yield is to seek the difficulty and correct that before considering what plant food to supply and how to supply it.

There are many ways open to correct the difficulties enumerated above, such as irrigation, drainage, deep culture, better plowing, more thorough harrowing and pulverization, mucking, liming, marling, etc. It is only by fully utilizing these means that the land will be in shape to receive artificial applications of plant foods, and that crops may use and benefit by such applications. In fact, applying artificial plant foods under many of these adverse conditions actually works harm instead of good. Deep, well-tilled, well-drained, non-acid loam containing a fair amount of organic matter or humus, and under good weather conditions, offers the best circumstances for a sure effect from the application of phosphates or any other plant food, and every means which improves these conditions will contribute towards the success of such applications.

How much phosphate to apply, as with other plant foods, will depend upon the requirements of the crops grown with reference to the soil in question.

Luxuriant plant growth or large crops and intensive soil culture are synonymous with the rapid conversion of plant food into crops. The demand for plant food must, therefore, be greatest where the consumption is greatest as will be indicated by the yield of the crop. This demand must be supplied, either from rendering the natural plant foods of the soil available or else they must be supplied through artificial applications. Hence, the quantity of phosphoric acid to apply must be regulated with reference to the natural soil supply and the requirements of the crops being grown.

From what has been said it must not be inferred that phosphoric acid can only be applied advantageously on the better grades of soils. This would be absolutely incorrect, for under favorable circumstances relatively larger results are secured from the application of phosphates on poor and even neglected and exhausted soils, but in such cases the applications should be made with greater precaution and intelligence as the conditions are more special and entail greater risks than on soils in better condition.

The points as to what kinds of phosphates to use in particular cases and how to use it, will develop in connection with the discussion of different phases of the subject as presented in the subsequent pages, and each person will need to study this portion of the subject and make such application as may seem best under the particular circumstances with which it is being dealt.

POINTS AFFECTING THE AVAILABILITY OF PHOSPHATES.

The form in which phosphoric acid offers the best all-round advantage to the practical farmer is a very delicate and difficult one to determine. Reasoning on the basis of the generally admitted theory that all elements must be in solution before they can enter into the interior of plants, it would then naturally follow that preference will be given to those phosphates which are most readily soluble or subject to dissociation. This will depend principally upon two conditions

1. The form and general characteristics of the phosphate.

2. The nature and composition of the soil to which the particular phosphate is applied.

In general, phosphates with the same chemical and physical characteristics are equally valuable when used under like conditions, no matter from what source they have been obtained. The many factors which enter into the availability of phosphates can be con-

sidered more in detail in connection with the results of some experiments treated of later in this bulletin, but a brief summary of the principal points will be given in the following paragraphs.

THE INFLUENCE OF THE CHARACTER OF THE SOIL UPON THE AVAILABILITY.

The kind and character of the soil may influence the ease and rate at which plants may be able to use the phosphate which is applied. A soil which is open and porous, and which admits of a free circulation of air and water, presents more favorable conditions for the crops using the phosphates than on a close, compact soil.

There is a marked difference in the availability of phosphate dependent upon the origin of the soil, and, hence, upon the chemical and physical properties. Many phosphates will act well on clay soils that are poorly adapted to the sandy soils, and some difference is manifestly due to the different chemical properties of various clay and sandy soils, dependent upon their origin.

THE EFFECT OF ORGANIC MATTER UPON THE AVAILABILITY OF PHOSPHATES.

Organic matter exerts a marked influence upon the physical properties of a soil and, hence, in this way alone, may aid in making applications of phosphate available. The formation of humic acid and humates also works beneficial results. Again, the organic matter is constantly undergoing more or less decomposition and thus giving off carbonic acid gas, which unites with the soil water. Water so charged has a greater dissolving action upon phosphates than ordinary rain water, hence, the presence of organic matter may render many phosphates available which would be entirely useless in the same soil without the organic matter.

Some experiments conducted by Bretschneider to determine the relative solubility of some phosphates in pure water and water charged with carbonic acid show that one part of phosphoric acid was dissolved in the several substances as follows

	Parts of pure water.	Parts of carbonic acid water.
Precipitated tri-calcium phosphate, fresh,	87,832	13,181
Precipitated tri-calcium phosphate, ignited,	159,532	13,324
Precipitated di-calcium phosphate, fresh,	29,350	8,916
Ammonia and magnesia phosphate,	21,957	1,969
Precipitated iron phosphate, fresh,	160,625	146,570
Precipitated iron phosphate, ignited,	732,958	732,958
Bone black finely powdered,	....	249,480

Several investigators have tested the solubility of rock phosphates in humic acids and in humates of ammonia, and it has been shown that the humic acids have really a considerable solvent power for phosphates, which would seem to explain the good effects produced by certain phosphates on peaty or muck soils.

INFLUENCE OF THE KIND OF CROP UPON THE AVAILABILITY.

The root system and habit and periods of growth vary considerable in different classes of crops, and hence their ability to get at and use plant foods, which accounts for some crops using insoluble phosphates more readily than others.

For instance, some experiments seem to show that turnips possess to an especial degree the ability to feed upon undissolved phosphates, while potatoes seem to have but little ability in this direction.

THE INFLUENCE OF THE SOURCE OF THE PHOSPHATE UPON ITS AVAILABILITY.

As has been stated, the availability of a phosphate depends upon the source and the relation which it bears to the soil, the crop and the conditions under which it is applied. So that phosphate which is available under one condition may be unavailable under another.

If the availability of phosphate used depends upon the changes which take place after it is applied to the soil, it will generally be found that organic phosphates will act quicker than those of mineral origin, as all organic matter is subject to decay and thus responds to the action of the natural agencies which exist in most cultivated soils. While the mineral phosphates are fixed and more or less stable compounds, which, if not natural to crops become so but slowly, as they yield very gradually to chemical changes.

When the material is being used in a dissolved condition it makes but little difference whether it is derived from the animal or mineral source.

THE AVAILABILITY AND LASTING EFFECTS OF PHOSPHATES AS DETERMINED BY MECHANICAL CONDITION OR DEGREE OF FINENESS.

The finer or more highly sub-divided a material is the greater surface it presents and, hence, the more easily is it acted upon by either organisms of decay or dissolved by the soil water, or the solution sent out by the roots of plants for the purpose of preparing plant food.

The finer the material the more easily is it disseminated in the soil and consequently placed in better position to be used by plants.

The chief ultimate value, as explained elsewhere, in reducing the phosphate to a soluble condition is the fine division and great dissemination which they get in the soil by being reverted or precipitated.

There is no particular classification of most phosphates, particularly the dissolved goods, with reference to mechanical condition, but with raw bones all fertilizer controls adopt a standard of fineness and base the valuation accordingly. The following are the standards and values in common use at this time:

Standard of Fineness.	Value of Phosphoric Acid.
Fine, less than 1-50 inch,	5 cents per pound.
Medium fine, 1-25 to 1-50 inch,	4 cents per pound.
Medium, 1-12 to 1-25 inch,	3 cents per pound.
Coarse, larger than 1-12 inch,	2 cents per pound.

In the early days of the use of bones as fertilizers they were applied in a very coarse condition, but as their use grew they were made finer and finer, until, in some cases, they were reduced to an impalpable powder. To reduce the bone to powder is too expensive, but now, in most cases, they are ground quite fine. Considerable study of the question of the rapidity of the availability of bones and phosphates has been made in Great Britain in connection with the tenant system of that country, so that due credit could be given for the amount remaining in the soil a given period after application with the various systems of farming. The degree of fineness of bones was an important factor in this valuation.

THE LIMING OF LAND AND ITS EFFECT UPON THE AVAILABILITY OF PHOSPHATES.

There has been considerable said from time to time upon this point, and there seems to be considerable difference of opinion expressed. No doubt there are some soils and circumstances which will produce directly opposite results when the land is limed either directly before or after the application of phosphates. The opinions expressed as a result of the first experiment conducted by the French chemists upon this point were to the effect that lime and phosphates were incompatible, as the soil water had a greater dissolving action on carbonate of lime than on phosphates, so prevented the crops using the phosphate. Be this as it may, there seems to be but little evidence that such is the result in practice, as in very many cases increased yields follow such combinations. This opinion seemed to be substantiated to the greatest extent on the soils already rich in carbonate of lime. On soils that are deficient in lime there seems, on the contrary, to be a benefit from the use of lime and phosphates in conjunction. While it is doubtful if these should be applied either at the same time or very close together,

yet if there is a reasonable time elapsed after the application of the lime and the lime had been thoroughly incorporated with the soil before putting on the phosphate it would seem from theory and also from the results of practice that the lime would aid in the forming of more desirable compounds with the soluble phosphoric acid than would be formed by a union of phosphoric acid with either iron or alumina. Again, on land that has been limed, the precipitation or reversion of the soluble phosphates would take place promptly and thus prevent harm that might come from the acid condition of the soluble phosphates when they come in close contact with young tender roots of plants and germinating seeds.

HOW SHALL PHOSPHATES BE APPLIED, BROADCAST OR IN THE HILL OR DRILL?

The question is frequently asked as to how phosphates and, in fact, fertilizers in general, should be applied. From what has already been said on the point of the desirability of thorough dissemination of phosphates of all sorts and of getting the soluble phosphates incorporated with the soil so that reversion shall promptly take place, and not subject the young and tender rootlets to injury from the acid and soluble phosphates, it would seem that there should be but little doubt but that the best way to apply phosphates would be to broadcast them and to have the broadcasting done so as to get as thorough a distribution as possible.

Again, in the case of the soluble, or acid phosphates, the principal value ultimately gained by the treatment with acid is the obtaining of the phosphates in a very finely divided state and getting it widely disseminated. The full value of these points is only obtained by broadcasting the fertilizer.

There is still another and very important point to consider in this connection, and that is the means by which plants feed. Plants obtain their food through the roots and the most active roots are the young and fibrous ones. A study of the root systems of all our common plants will be a great surprise to anyone who makes the study or examination for the first time. The area and depth covered by the roots of all our plants will astonish most farmers who have never considered the matter. When corn is but six or eight inches high the roots of the plant will often be found to be extended out two or three feet in all directions, or to be running from row to row and going much deeper than is ordinarily plowed. The roots of a tobacco plant will almost always cover two or three time as great a surface as the leaves of the plant can shade. Even the roots of potato plants before maturity will extend from row to row under the common system of planting.

Now, taking these facts as to the root system into consideration, it would seem to present another strong argument in favor of broadcasting the fertilizer. Wide distribution also brings the phosphates in contact with a greater amount of soil waters and thus increases their availability. In case of raw bone, broadcasting would favor decomposition and the natural agencies for rendering it available. Putting bone, acid and other organic fertilizers in the hill will often produce fermentation that will kill the germinating seed.

There are times and circumstances, however, when it probably would be advantageous to apply phosphates, or even other fertilizers in the hill or drill. Such cases would probably be caused by the following considerations:

1st. When very small quantities were being used and it was only desired for the purpose of giving the crop a rapid start, while the natural fertility was sufficient for growing a good crop after it was well started.

2d. Under some circumstances the application in the hill or drill would have a tendency to retard the reversion of the soluble phosphates and thus keep it for a longer time in a form more available to certain crops. This consideration may obtain in some cases with such crops as potatoes.

3d. The application of small quantities of phosphates and other fertilizers (particularly kainit) will sometimes protect plants from cut worms and root lice in the early stages of their growth.

Putting fertilizer in the hill has been likened to a man sitting down on his dinner pail and then reaching out for his dinner in all directions, but there is no doubt that in some cases and with some plants it is just as easy for the roots to reach and feed on the fertilizer in the hill as it would be for a man to utilize the dinner under such circumstances.

Taking everything into consideration, it would probably be best, under ordinary circumstances, to always apply phosphates broadcast and only put it in the hill when guided by special conditions.

THE AGRICULTURAL AND COMMERCIAL VALUE OF PHOSPHATES.

Notwithstanding the numerous explanations that have been made in the agricultural press, in bulletins and by lecturers at farmers' institutes, etc., of the difference between the agricultural value and the commercial value of fertilizers, farmers are continually confounding the two values, and falling into the error that because one fertilizer has a higher commercial value than another it must necessarily have a higher agricultural or fertilizing value as well.

The commercial value of a fertilizer depends upon its abundance, the ease with which it is produced and the amount being

used, or, in other words, upon the ever-ruling elements in the commercial world of "Supply and Demand."

The agricultural value depends upon the ability of the particular fertilizer or phosphate in question to improve the fertility or productive capacity of a particular soil. Hence, it will be seen that the agricultural value, within certain limits, is not directly dependent upon the commercial value (and vice versa), and is a value that changes with different soils.

To illustrate; suppose a particular class of soils contain all the phosphates necessary for crops and that the application of any more phosphates give no returns whatever in increasing yields. This would mean that for that particular piece of land phosphates had *no value agriculturally*; yet that would not affect the market or commercial value of the phosphate. To illustrate further; sugar has a commercial value of $100.00 per ton, while Dissolved South Carolina rock can be purchased for one-tenth that sum. From a fertilizing standpoint, it is doubtful if an application of sugar would have any effect on the yield of crops, while the phosphate might double them, and thus have double the agricultural value of the sugar. Again, clover hay, for instance, has double the fertilizing and feeding value of timothy hay, yet the commercial or market value of timothy hay is always the more.

The following is the commercial value of phosphoric acid in different phosphatic materials according to the trade valuations in Pennsylvania in 1901:

	Cents per pound.
Soluble phosphoric acid in bone fertilizers,	5
Soluble phosphoric acid in rock fertilizers,	3
Reverted phosphoric acid in bone fertilizers,	4½
Reverted phosphoric acid in rock fertilizers,	2½
Insoluble phosphoric acid in bone fertilizers,	2
Insoluble phosphoric acid in rock fertilizers,	1½
Total phosphoric acid in fine raw bone, tankage and fish fertilizer,	3½
Total phosphoric acid in medium bone and tankage,	3
Total phosphoric acid in coarse bone and tankage,	2½
Total phosphoric acid in cotton-seed meal,	4
Castor pomace and wood ashes,	4

From these figures it will be seen that the commercial or trade value of 100 lbs. of soluble phosphoric acid in a dissolved bone would be $5.00, while 100 lbs. in a dissolved rock would be but $3.00. From an agricultural standpoint, in view of all the experiments which have been conducted, the value of phosphoric acid from the two sources would be exactly the same.

Again, the above valuations place a higher valuation upon the total phosphoric acid in cotton-seed meal than that from bone, whereas, when applied, probably there would be no difference so far as phosphoric acid is concerned.

From what has been said it would be plain to every farmer that he should buy a phosphate or, indeed, any fertilizer with reference to the value it has to him in increasing the productive capacity of his soil and not purchase solely upon the basis of commercial valuations as represented by agents or tabulated analysis of fertilizers.

THE DETERMINATION OF AVAILABLE PHOSPHORIC ACID IN SOILS.

The purpose of the agricultural chemical examination of soils, from the earliest time when the science was employed in this way, was to throw some light upon the relations of the various constituents to plant growth and especially to determine the amounts of the essential constituents which are in a condition to be used by crops or, in other words, "available." There have been numerous methods proposed for distinguishing between available and unavailable plant foods in various kinds of soils, and this problem has occupied the attention of the best minds in agricultural chemistry for many years. No one element in this study has received as much attention as the phosphoric acid.

At the present day there seems to be a general agreement that the use of weak solutions or solvents give results that more nearly correspond to the results obtained by cropping, yet there is much difference of opinion as to the proper acid or solution to use. This condition, no doubt, is due to the variations in the chemical characteristics of the soils experimented upon.

The present status of the results obtained in this research would seem to indicate that it is very improbable that a marked distinction of any kind can be drawn between "available" and "unavailable" compounds of phosphoric acid in the soil, for the reason that it is not probable that any soil contains a compound or group of compounds which can be wholly removed by plants or dissolved by an acid that is "available," before the remaining compounds are attacked. From the very nature of the changes which are taking place in soils, produced either by crops or natural agencies, there must be more or less change and re-arrangement of the

elements as different ones are attacked, thus making some phosphates available that were previously unavailable, or even the reverse may take place.

It is probable that of the many methods proposed that none of them will be equally well adapted to all classes of soils owing to the selective power of certain acids for different combinations of phosphoric acid, and they will attack different types of soils with more or less vigor, but in the main the *relative* action of all acids on all soils will be alike.

Hall and Plymen have recently made an extensive research and review of the methods proposed for available phosphoric acid, and have reached the conclusion that one per cent. solution of citric acid gave results which are most in accord with the known history of soils. On soils well provided with carbonate of lime, there was little difference in the results obtained with the different acids tried.

With the present state of the perfection of chemical analysis of soils it will still be necessary to put much reliance upon the results obtained by the practical use of the various phosphates in connection with the growing of different crops upon a variety of soils. Upon the following pages will be given brief summaries of prominent experiments of this character.

EXPERIMENTS WITH DIFFERENT FORMS AND SOURCES OF PHOSPHORIC ACID.

Almost as soon as the value of phosphoric acid began to be recognized as an essential plant food, various experiments were conducted as to the value of the phosphoric acid from different materials and sources. These experiments have been repeated from time to time under varying conditions and circumstances. The experiments upon points which seem to have particular value to the farmers in the United States are those conducted at the Pennsylvania Experiment Station and at the Maryland Agricultural Experiment Station. These two series of tests have been performed upon two distinct classes of soils, which are representative of a large percentage of those commonly cultivated, and the conditions under which the tests were carried on are fairly representative of ordinary farm practice. So the results would seem to have much value for practical application.

Article on the determination of available Plant Food, Jour. Chem. Soc., Lond., Jan., 1902, pp. 117-144.

EXPERIMENTS AT THE PENNSYLVANIA STATION, WITH SOLUBLE, REVERTED AND INSOLUBLE PHOSPHORIC ACID.

These experiments had for their object the testing of the value of the different forms of phosphoric acid in actual crop production, as compared with their cost in the market. These experiments were planned by Dr. W. H. Jordan, now director of the New York Agricultural Experiment Station at Geneva, and have been in progress since 1883, or nearly twenty years.

The soil of the plots used in this test is a so-called limestone clay, formed from the decomposition of the surrounding and underlying rock, which is very largely magnesia and limestone. It has the general appearance of a clay loam. Previous to the adoption of this land to the experiments under consideration, it was farmed under the general four or five years' rotation of that section, which includes turning under a good sod every four or five years, and thus the land contained a fair amount of organic matter. The plots were laid out in the spring of 1883. In 1879 and 1881 the land was in grass (clover and timothy) and in 1882 in potatoes. No manure was applied to either crop. The first year the plots were seeded to oats and no fertilizer of any kind was applied, so that some idea could be gained as to the uniformity of the land. In the general work the four year's rotation, common to that part of the State, was adopted, viz: oats, wheat, grass, corn. The fertilizer was applied but twice in the rotation just previous to seeding to wheat and planting to corn.

The last report made upon the results of these tests is contained in the annual report of the Pennsylvania Experiment Station for 1895, and covers the work for twelve years, or three rotations. The kind and amount of fertilizer applied is shown in the following table:

TABLE 9.

Kind and Amount of Fertilizer Applied to the Different Plots.

Plots.	Kind of Fertilizer.	Quantity applied per acre—Lbs.	Quantity of valuable ingredients applied per acre.		
			Nitrogen—Lbs.	Phosphoric acid.	Potash—Lbs.
A & G	Soluble phosphoric acid (dissolved bone black),	200	...	32	...
	Muriate of potash,	200	...	...	100
	Sulphate of ammonia,	240	47	...	...
B & H	Reverted phosphoric acid (dissolved bone black treated with an equal weight of quick lime,	200	...	32	...
	Muriate of potash,	200	...	...	100
	Sulphate of ammonia,	240	47	...	...
C & I	Insoluble phosphoric acid (fine ground bone),	150	4	40	...
	Muriate of potash,	200	...	...	100
	Sulphate of ammonia,	240	47	...	...
D & J	Insoluble phosphoric acid (ground South Carolina rock),	150	...	40	...
	Muriate of potash,	200	...	...	100
	Sulphate of ammonia,	240	47	...	...
E & K	Muriate of potash,	200	...	...	100
	Sulphate of ammonia,	240	47	...	...
F & L	Nothing,	...	...	...	...

The following is a summary of the results as given in that report:

SUMMARY OF YIELD AND VALUE OF CROPS.

WHEAT.

Taking the average for the three years, 1884, 1888 and 1892, insoluble phosphoric acid in the form of ground bone, and the insoluble phosphoric acid in the form of ground South Carolina Rock gave practically identical results, no phosphoric acid, stood third in grain and fifth in straw, reverted phosphoric acid in the form of dissolved bone black treated with an equal weight of lime, fourth in grain and third in straw, and soluble phosphoric acid in the form of dissolved bone black, fifth in grain and fourth in straw.

TABLE 10.

Average Yield Per Acre of Wheat of Plots.

Plot.	Form in Which it Was Applied.	Source of Supply.	Amount applied—Lbs.	Average.			
				Grain.			
				Lbs.	Bushels. (60 lbs.)	Straw—Lbs.	Total—Lbs.
A & G	Soluble phosphoric acid, ...	Dissolved bone black, ..	200	1,694	28.23	3,014	4,708
B & H	Reverted phosphoric acid, ..	Dissolved bone black,* .	200	1,794	29.90	3,208	5,002
C & I	Insoluble phosphoric acid, ..	Ground bone, ...	150	1,895	31.58	3,339	5,234
D & J	Insoluble phosphoric acid, ..	South Carolina rock, ...	150	1,894	31.56	3,338	5,232
E & K	No phosphoric acid, ...	....	......	1,834	30.57	2,798	4,632
F & L	Nothing, ...	....	......	1,351	22.52	1,966	3,317

*Treated with an equal weight of quick lime twelve hours before application.

Assuming the yield of the plots receiving no fertilizer to be 100, the average yield of the different plots is as follows:

Plot.	Form in Which it Was Applied.	Source of Supply.	Amount applied—Lbs.	Average.		
				Grain—Lbs.	Straw—Lbs.	Total—Lbs.
A & G	Soluble phosphoric acid, ...	Dissolved bone black, ...	200	125	153	130
B & H	Reverted phosphoric acid, ..	Dissolved bone black Dissolved bone black and lime,	200	133	163	138
C & I	Insoluble phosphoric acid, ..	Ground bone, ...	150	140	170	145
D & J	Insoluble phosphoric acid, ..	South Carolina rock, ...	150	140	170	145
E & K	No phosphoric acid, ...	....	......	136	143	137
F & L	Nothing, ...	....	......	100	100	100

The value of the crop per acre for the different fertilizers applied is shown in the following table:

TABLE 11.

Plots.	Form of Phosphoric Acid Applied in Connection with Nitrogen and Potash.	Source of supply.	Value of grain.	Value of straw.	Total value.
C & J	Insoluble phosphoric acid, ...	Ground bone, ...	$27 79	$6 68	$34 47
D & J	Insoluble phosphoric acid, ...	South Carolina rock, ...	27 77	6 68	34 45
B & H	Reverted phosphoric acid, ...	Bone black and lime, ..	26 32	6 42	32 74
E & K	No phosphoric acid, ...	....	26 90	5 60	32 50
A & G	Soluble phosphoric acid;	Bone black, ...	24 84	6 03	30 87
F & L	Nothing, ...	....	19 82	3 93	23 75

HAY.

Taking the average for the three years, 1885, 1889 and 1893, insoluble phosphoric acid (ground bone) was first, reverted second, soluble third and insoluble (South Carolina rock) fourth.

TABLE 12.

Average Yield of Grass (Hay) per Acre.

Plot.	Form of Phosphoric Acid Applied.	Total yield.	Average for Three Years. Yield.	Average for Three Years. Proportionate yield.
A & G	Soluble phosphoric acid, ...	9,500	3,167	155
B & H	Reverted phosphoric acid, ...	9,900	3,300	161
C & I	Insoluble phosphoric acid, ...	10,095	3,365	164
D & J	Insoluble phosphoric acid, ...	9,400	3,133	153
E & K	No phosphoric acid, ...	7,475	2,492	122
F & L	Nothing, ...	6,145	2,048	100

The value of the crop per acre for the different fertilizers applied is shown in the following table:

TABLE 13.

Average Yearly Value of Hay per Acre.

Plots.	Form of Phosphoric Acid Applied in Connection with Nitrogen and Potash.	Form in which the Phosphoric Acid Was Applied.	Value.
C & I	Insoluble phosphoric acid,	Ground bone,	$18 69
B & H	Reverted phosphoric acid,	Bone black and lime,	18 33
A & G	Soluble phosphoric acid,	Bone black,	17 59
D & J	Insoluble phosphoric acid,	South Carolina rock,	17 41
E & K	No phosphoric acid,		13 84
F & L	Nothing,		18 38

CORN.

Taking the average for the three years, 1886, 1890 and 1894, insoluble phosphoric acid (ground bone), was first in the yield of grain and stover, reverted second in grain and third in stover, soluble third in grain and second in stover, and insoluble (South Carolina rock) fourth in grain and stover.

TABLE 14.

Average Yield of Corn Plots.

Plots.	Form of Phosphoric Acid Applied.	Average. Ears. Lbs.	Average. Ears. Bushels 70 lbs.	Average. Stover.	Average. Total—Ears and stover.	Average. Proportionate. Ears.	Average. Proportionate. Stover.
A & G	Soluble phosphoric acid,	3,420	48.86	1,942	5,362	148	189
B & H	Reverted phosphoric acid,	3,472	49.60	1,937	5,409	150	189
C & I	Insoluble phosphoric acid,	3,637	51.96	2,073	5,710	157	202
D & J	Insoluble phosphoric acid,	3,335	47.64	1,908	5,243	144	186
E & K	No phosphoric acid,	2,848	40.68	1,667	4,515	123	162
F & L	Nothing,	2,315	33.07	1,027	3,342	100	100

The value of the crop per acre for the different fertilizers applied, is shown in the following table

TABLE 15.

Average Yearly Value of Corn Per Acre.

Plots.	Form of Phosphoric Acid Applied in Connection with Nitrogen and Potash.	Form in which the Phosphoric Acid was Applied.	Value of ears.	Value of stover.	Total value.
C & I	Insoluble phosphoric acid, ...	Ground bone, ...	$27 54	$5 19	$32 73
B & H	Reverted phosphoric acid, ...	Bone black and lime, ..	26 29	4 84	31 13
A & G	Soluble phosphoric acid, ...	Bone black, ...	25 89	4 86	30 75
D & J	Insoluble phosphoric acid, ...	South Carolina rock, ...	25 25	4 78	30 02
E & K	No phosphoric acid, ...	....	21 56	4 17	25 73
F & L	Nothing, ...	....	17 52	2 57	20 09

OATS.

Taking the average for the three years, 1887, 1891 and 1895, insoluble phosphoric acid (ground bone) was first in the yield of grain and straw and weight per bushel, insoluble (South Carolina rock) second in grain and straw and fourth in weight per bushel, reverted third in grain, fourth in grain and fifth in straw and weight per bushel, soluble fifth in grain and third in straw and weight per bushel.

TABLE 16.

Average Yield Per Acre of Oats.

Plot.	Form of Phosphoric Acid Applied.	Average.					Average for three years.			
		Grain.								
		Lbs.	Bus.—(32 lbs.)	Straw—Lbs.	Total grain and straw—Lbs.	Weight per bushel. Lbs.	Grain—Bus. (32 lbs.).	Straw—Lbs.	Total—Lbs.	Weight per bushel—Lbs.
A & G	Soluble phosphoric acid, ...	1,400	43.75	1,337	2,737	39	113	122	117	105
B & H	Reverted phosphoric acid, ...	1,507	47.10	1,326	2,833	39	121	121	121	106
C & I	Insoluble phosphoric acid, ...	1,580	49.39	1,595	3,175	39	127	146	136	106
D & J	Insoluble phosphoric acid, ...	1,544	48.24	1,557	3,101	38	124	142	133	104
E & K	No phosphoric acid, ...	1,457	45.54	1,217	2,674	38	117	111	114	104
F & L	Nothing, ...	1,242	38.81	1,095	2,337	37	100	100	100	100

The value of the crop per acre and weight per bushel for the different fertilizers applied, are shown in the following table

TABLE 17.

Average Yearly Value of Oats Per Acre.

Plots.	Form of Phosphoric Acid Applied in Connection with Nitrogen and Potash.	Form in which the Phosphoric Acid Was Applied.	Value of grain.	Value of straw.	Total value.	Weight per bush—Lbs.
C & I	Insoluble phosphoric acid, ...	Ground bone, ...	$18 27	$3 19	$21 46	39 54
D & J	Insoluble phosphoric acid, ...	South Carolina rock,	17 85	3 12	20 97	38 66
B & H	Reverted phosphoric acid, ...	Bone black and lime,	17 42	2 65	20 07	39 47
E & K	No phosphoric acid, ...	....	16 85	2 43	19 28	38 66
A & G	Soluble phosphoric acid, ...	Bone black, ...	16 19	2 67	18 86	39 00
F & L	Nothing, ...	....	14 36	2 19	16 55	37 16

The conclusions, as set forth in the discussion of the above results, in the report, are as follows:

CONCLUSIONS FROM THE PENNSYLVANIA STATION EXPERIMENTS.

1. That soluble phosphoric acid is too expensive to be used by farmers having a limestone soil similar to the one on which this experiment was made, since fully as good results can be secured by the use of the much cheaper insoluble form.

2. That insoluble phosphoric acid in the form of ground bone is slightly superior to that in the form of South Carolina rock.

3. That corn is benefited more by the application of phosphoric acid than wheat, oats or grass (2-3 clover, 1-3 timothy).

EXPERIMENTS AT THE MARYLAND STATION.

These experiments were planned on a more extensive scale than those in Pennsylvania and were conducted with special reference to the making a study of the availability of the different sources of insoluble phosphates. The detailed report upon these experiments was made in Bulletin No. 68, of the Maryland Agricultural Experiment Station, published in September, 1900. The following gives a summary as to the plan of the experiments and results:

PLAN OF THE EXPERIMENTS CONDUCTED.

The general plan of the experiments conducted in the testing of the availability of different forms of phosphoric acid and means for rendering insoluble phosphates available in the soil. The idea in mind was to make these tests much more than a soil test of this

particular farm, but they were so planned and conducted as to make the results applicable to most parts of this State, and of general interest to agriculture wherever commercial fertilizers are used.

The general idea that pervaded the plan was to imitate nature and get the land as nearly as possible in the same condition it was when a virgin soil and then continue to use nature's methods for maintaining fertility.

It is well known from chemical analysis of soils that they contain sufficient phosphoric acid to furnish all that is needed for good crops for many years. It has also been shown that some soils which fail to produce satisfactory crops contain more phosphoric acid than those that are considered fertile. Now, this difference in fertility must be due to a condition of availability.

An examination of the conditions which prevailed in virgin soils, or in any soil that has just been cleared of its forest growth, soon makes prominent the fact that nature has filled that soil with organic matter; this organic matter not only gives the soil a dark color and fine physical appearance, but it also performs functions in producing chemical changes that cannot take place in that same soil were it destitute of organic matter. Again, we find that a virgin soil will produce satisfactory crops for a number of years without the intervention of commercial fertilizers, but about as soon as the organic matter has been worked out, the soil fails to produce satisfactory crops and the use of phosphates is resorted to.

Now, the phosphoric acid which these soils contained was not in a form soluble in water, nor was it in the form of reverted or dicalcium phosphates, but it was an insoluble phosphate of lime, magnesia, iron or alumina. Though termed insoluble, yet this phosphoric acid was available to crops, through the chemical changes made possible by the presence of organic matter and the compounds formed through its decomposition. It was the water charged with carbonic, humic and other organic acids, formed by the decomposition of vegetable matter, that was able to dissolve the insoluble phosphates of the virgin soils and place them either directly at the disposal of crops, or from such combinations as could be be utilized thereafter.

As soon as the organic matter of the soil was used up, these favorable conditions no longer obtained, and crops could not avail of the natural properties of the soil even though there was an abundance present. Now, if nature's methods are observed again, it will be noticed that wherever she is producing vegetation she has devised means for depositing some vegetable matter in the soil in about the same proportion as she produces.

Taking all these facts into consideration would it not seem reasonable that, in order to avail properly of the phosphates contained

naturally in the soil, that it would be necessary to imitate nature's methods and fill the soil with organic matter. Then, again, could not the phosphoric acid contained in the mineral phosphates be rendered available in the soil through the agency of organic matter if these phosphates were applied in their natural state, except being pulverized? If these questions be answered in the affirmative, and the farmer can arrive at an economical and satisfactory method of providing the requisite amount of organic matter in the soil, then it will be possible to avail of the phosphates already in the soil, and thus, on some lands, make it unnecessary to purchase phosphoric acid. When recourse to purchase becomes necessary, then a cheaper form of phosphoric acid can be used and do away with paying out so much money for dissolved or acid treated phosphates, which, in the end, is practically a means of accomplishing or arriving at a mechanical condition.

These are the ideas that call for the planning and management of the experiments outlined in the following program:

TABLE 18.
Phosphoric Acid Experiments.
(Plots One-Tenth of an Acre Each.)

Plot number.	Kind of Fertilizer and Treatment.	Quantity* per plot—Lbs.	Quantity per acre—Lbs.
	CRIMSON CLOVER SEEDED IN CORN.		
1	Double super-phosphates (Soluble P_2O_5),	32	319
2	Dissolved bone black (Soluble P_2O_5),	73½	735
3	Dissolved South Carolina rock (Soluble P_2O_5),	100	1,000
4	Double super-phosphates (P_2O_5),	37	370
5	Nothing,	....	....
6	Iron alumina phosphate (Reverted P_2O_5),	37	370
7	Bone black (Insoluble P_2O_5),	51½	514
8	Raw bone meal (Insoluble P_2O_5),	66¾	667
9	Slag phosphate (Insoluble P_2O_5),	92	920
10	Nothing,	....	....
11	Ground South Carolina rock (Insoluble P_2O_5),	53	560
12	Florida soft phosphate (Insoluble P_2O_5),	56	560
	CORN GROUND LEFT BARE DURING WINTER, NO GREEN CROP TURNED UNDER.		
13	Same as No. 8,	66¾	667
14	Same as No. 9,	92	920
15	Nothing,	....	....
16	Same as No. 11,	53	530
17	Same as No. 12,	56	560
	RYE SEEDED ON CORN GROUND.		
18	Same as No. 8,	66¾	667
19	Same as No. 9,	92	920
20	Nothing,	....	....
21	Same as No. 11,	53	530
22	Same as No. 12,	56	560

*These quantities give each plot the same quantity of phosphoric acid (150 pounds per acre, which was determined by analyzing the materials used).

The piece of land used for these experiments lies north of the Experiment Station buildings and along the fence west of the pike. This land is a moderately stiff clay, naturally quite well drained, though fairly level. The general character of the plots runs quite uniform, in fact more so than most pieces of like area in this formation. This land is of water formation and contains iron and alumina and is very deficient in lime.

The history of the cropping of the land used for this test was, so far as known, as follows: In 1888 there was a poor stand of grass and weeds on this land, which was plowed down and seeded to wheat, which was harvested in 1889; grass 1890-91; corn 1892; fallowed 1893, and in wheat 1894—clover and timothy seeded in wheat and gave a good set.

TABLE 19.

Showing Summary of Yields with Different Forms of Phosphoric Acid.

(In Pounds Per Acre.)

	3 Corn Crops.		Wheat.			Total product—5 Crops.		
	Grain—Lbs.	Fodder—Lbs.	Grain—Lbs.	Straw—Lbs.	Hay—Lbs.	Grain—Lbs.	Fodder—Lbs.	Total—Lbs.
Average of 4 nothing plots (5, 10, 15, 20),	9,203	7,387	1,309	2,601	3,862	10,512	13,850	24,362
Average of 3 soluble phosphoric acid plots (1, 2, 3),	9,095	7,453	2,203	3,815	4,350	11 298	15,618	26,916
Average of 2 reverted phosphoric acid plots (4, 6),	9,590	8,035	1,936	3,360	4,525	11,526	15,920	27,446
Average of 5 insoluble phosphoric acid plots, crimson clover turned under (7, 8, 9, 11, 12),	10,073	7,610	1,864	3,837	4,020	11,937	15,467	27,404
Average of 4 insoluble phosphoric acid plots, crimson clover turned under (8, 9, 11, 12),	10,201	7,620	1,946	3,942	4,025	12,147	15,587	27,734
Average of 4 insoluble phosphoric acid plots, nothing turned under (13, 14, 16, 17),	9,615	8,033	2,025	3,611	3,838	11 640	15,481	27,121
Average of 4 insoluble phosphoric acid plots, rye turned under (18, 19, 21, 22),	8,850	7,315	2,012	3,511	3 900	10,862	14,726	25,588
Average of 12 insoluble phosphoric acid plots (8, 9, 11, 12, 13, 14, 16, 17, 18, 19, 21, 22),	9,555	7,656	1,994	3,688	3 921	11,549	15,265	26 814
Average of 3 bone meal plots (8, 13, 18),	10,029	7,907	2,120	3,903	3 867	12 149	14 677	26,826
Average of 3 slag phosphate plots (9, 14, 19),	9,625	7,647	2,160	4,195	4 217	11,795	16,059	27,854
Average of 3 South Carolina rock plots (11, 16, 21),	9,294	7,593	1,890	3,508	4,217	11,184	15,318	26 502
Average of 3 Florida soft phosphate plots (12, 17, 22),	9,273	7,477	1,800	3,147	4,050	11,073	14,674	25,747

DISCUSSION OF MARYLAND STATION RESULTS.

The matter of drawing conclusions from results obtained from plot experiments is always attended with more or less uncertainty, as soil and weather variations will often bring about what may seem to be contradictions. There are, also, often uncontrolable and unnoticed errors produced by the depredations of birds, mice, insects, etc. While these may be very small in themselves, yet when the error is multiplied to represent yields per acre, it may amount to considerable. In order to obviate some of these difficulties, there has been no report made on the experiments under discussion until they have been through five years, and covered several kinds of crops. Even a longer period than this would be desirable, as it would probably serve to confirm some conclusions and to eliminate some doubtful points. These tests will be continued for some years.

The quantities of phosphoric acid applied in these tests are rather more than was necessary and more than would be found economical in practice, but it was thought best in planning the experiments to have an excess present and so endeavor to make the results more pronounced, than to attempt to run on the basis of greatest profit. It was the principles of phosphoric acid fertilization that were desired to be established rather than the limits of the soil requirements.

Nothing Plots (Nos. 5, 10, 15, 20). An examination of Table 19, page 62, shows that the average total product from the plots receiving no fertilizer was considerably below the average yields of all the plots which were fertilized. With some crops there was little increase in the yield through fertilization, and in a few instances the *nothing* plots made a slightly higher yield than those fertilized. This is notably the case with corn. The unfertilized plots of corn made a better average yield than those receiving the soluble phosphoric acid with rye turned under. The failure of the phosphoric acid plots to outyield the *nothing* plots was probably due, in a measure, to the phosphate being very available to the plant, over-stimulated it in the start, and this produced in the plant a condition which made it not so able to withstand the period of drought later in the season and at a time when the grain was forming and there was greatest call for food and activity. This is borne out in a measure by a comparison of the detailed yields as given in Table 19, with the rainfall for that period. There is also a probability that the soluble phosphoric acid, when it entered the soil, was precipitated and formed unions which were not available to the crops, but this condition would not likely produce a decrease in the yields. All of the fertilized plots made very decidedly larger yields

of wheat than the *nothing* plots, which would seem to show that the feeding habit of wheat is very different from corn and that it particularly benefitted by the addition of phosphoric acid.

Soluble Phosphoric Acid (Nos 1, 2, 3). The figures in Table 19 show that all the other forms of phosphoric acid gave higher total yields in five years than the soluble phosphoric acid, except on the plots where rye was turned under. The slightly higher total yield in the case of the rye turned under is accounted for in the corn crops, and is probably due to the rye decomposing slowly and causing the soil to dry out easily, have a poor physical condition and thus suffer from drought. Soluble phosphoric acid seems to be particularly beneficial to wheat where it gave the highest average yield. The probable failure of soluble phosphoric acid to give good yields on corn has been discussed under the *nothing* plots.

A comparison of the different sources of soluble phosphoric acid shows the total yield to stand in favor of the most concentrated fertilizer, or in the order of the plot Nos. 1, 2, 3. The wheat yield was in favor of the dissolved bone black, and hay was best on the dissolved South Carolina rock plots. This was probably due to the action of the sulphate of lime in the dissolved goods, liberating and forming available combinations with the potash in the soil.

Reverted Phosphoric Acid (Nos. 4 and 6). Reverted phosphoric acid gave better total yields for the five crops and better average yields in corn and hay, than soluble phosphoric acid, though not quite so large a yield of wheat. This would seem to confirm the popular idea that reverted phosphoric acid has as great an agricultural value as soluble phosphoric acid. A comparison of reverted phosphate of lime and reverted phosphate of iron and alumina show in every instance with every crop to be in favor of the reverted phosphate of iron and alumina.

Insoluble Phosphoric Acid (Nos. 7, 8, 9, 11, 12, 13, 14, 16, 17, 18, 19, 21 and 22). An examination of Table 19 shows the average yield of five insoluble phosphoric acid plots (Nos. 7, 8, 9, 11 and 12) to have produced considerably more grain than either the soluble or reverted forms of phosphoric acid ,but the amount of fodder was slightly in favor of both the latter. The total product (grain plus the fodder) was more on the insoluble than on the soluble phosphoric acid plots, and within forty-two pounds as much as the reverted phosphoric acid. The value of these results is still further advanced when it is considered that the price of the insoluble phosphoric acid was only about one-half as much as that obtained in the soluble and reverted forms. The above comparisons include only Plots 1 to 12, as these were treated uniformly with respect to turning under crimson clover, green.

A comparison of the different sources of insoluble phosphoric acid as given by the figures in Table 19, page 62, shows slag phosphate to have produced the larger total yield (also a larger yield of both grain and fodder) than either soluble or reverted phosphoric acid. Bone meal produced a little more grain than any other form of insoluble phosphoric acid, but the cost per pound of plant food was about 50 per cent. more than that in the slag and three times as much as that in the South Carolina rock and Florida phosphates. The insoluble phosphate of lime, as furnished by the South Carolina rock, gave better results than the insoluble phosphate of iron and alumina as furnished by the Florida soft phosphate.

GREEN CROPS FOR TURNING UNDER WITH INSOLUBLE PHOSPHATES.

In order to test the value of green crops, or vegetable matter, for rendering insoluble phosphates available, four plots had crimson clover seeded in corn for turning under; four plots had rye in the same manner, while four others had no green crop turned under and were allowed to remain bare during the winter. These plots showed the average results to be considerably in favor of the crimson clover for this purpose. Part of the advantage of the clover no doubt existed in the nitrogen which it furnished and also in the available plant food which it brought from the sub-soil. The clover decomposes rapidly and aids the physical condition of the soil. The rye used seems to have been a disadvantage and did not give as good yields as when no green crop was used. This was particularly the case with the corn crop. The disadvantage rested, probably, in the rye decomposing slowly and thus producing a bad physical state at times and making the corn crop suffer from dry weather.

There is one fact worthy of note, though not directly concerning the experiment under discussion, and that is that by turning under a large amount of leguminous crop like crimson clover, corn can be successfully grown for a number of years in succession with increasing yields.

CONCLUSIONS FROM THE MARYLAND STATION EXPERIMENTS.

In the matter of drawing conclusions it is always well to be cautious and to err, if at all, on the side of conservatism. This policy is particularly well adapted with reference to the application of the results which have been obtained in the experiments under consideration and in using the conclusions that may be drawn.

There is no doubt that the results, as shown by the total product of the crops for five years (last column, Table 19, page 62), are, at

variance with the principles commonly taught and practice generally followed in the matter of fertilization. With these considerations it would be well for those persons who desire to apply these results or use any different source or form of phosphoric acid from that which has been successfully and satisfactorily used in the past, to do so on a limited scale in order to be satisfied that these results will hold under the new and different conditions which may surround each particular case.

The average total results, as given by the figures in Table 19, page 62, show that insoluble phosphoric acid, that is phosphates which have not been treated or dissolved in sulphuric acid (oil of vitriol), have more pounds of crop, both straw and marketable grain, than the phosphoric acid in the soluble and reverted forms; that is, in phosphates which have been dissolved in sulphuric acid. Not only has the yield produced by the insoluble phosphoric acid been greater than that produced by the soluble phosphoric acid, but the cost has been only about one-half as much.

The results obtained show that crops are able to use the insoluble phosphoric of South Carolina rock, notwithstanding the preaching and contention of most fertilizing manufacturers.

The results show that slag phosphate (which is mostly a tetraphosphate of lime, classed by some as available to crops, yet classed by the American Official Methods of Analysis as mostly insoluble phosphoric acid), gives a greater total yield than any of the other insoluble phosphates. The yield of corn (grain), though not quite as much with slag phosphate as with bone meal, yet was greater with wheat and grass. All yields were produced at a less cost with slag phosphates than with bone meal.

Bone meal was the best form of insoluble phosphate for corn, but its accumulative and supposed lasting effects did not show on the wheat and grass. Bone meal has also had an advantage over the other phosphates in furnishing some nitrogen.

The results obtained show crimson clover to be the best crop to use for obtaining organic matter in the soil in order to procure the best results with the insoluble phosphates.

SUMMARY OF PRINCIPAL RESULTS OBTAINED FROM THE MARYLAND STATION EXPERIMENTS.

1. All forms of phosphoric acid produced an increase of crop.

2. The average total yield of the crops fertilized with insoluble phosphoric acid was greater than those with the soluble and reverted forms of phosphoric acid.

3. Reverted phosphoric acid gave a greater total yield than soluble phosphoric acid.

4. Reverted phosphate of iron and alumina gave a higher yield than reverted phosphate of lime.

5. Soluble phosphoric acid gave slightly higher yields of wheat (grain) than phosphoric acid in any other form.

6. Concentrated sources of soluble phosphoric acid gave better results than the low grade sources.

7. Untreated South Carolina rock gave a higher total yield than dissolved South Carolina rock.

8. Slag phosphate produced a greater total yield and at less cost than the average of the soluble phosphoric plots and the bone meal plots.

9. Insoluble phosphoric acid from slag, produced a greater yield than the insoluble phosphoric acid from South Carolina rock and Florida soft phosphate, but at greater cost than the two latter.

10. For the best results with insoluble phosphates, it is desirable to have the land well filled with organic matter. Of the methods tested, crimson clover was the best means of obtaining this.

EXPERIMENTS OF THE OHIO STATION.

Tests have been conducted by the Ohio Agricultural Experiment Station upon the value of different sources of phosphoric acid, at three points in the State, viz: at Wooster, Strongsville and Columbus. The materials used in this test were raw bone meal, dissolved bone black, acid phosphate and basic slag phosphate.

The materials were applied so as to give each plot of ground the same number of pounds of phosphoric acid. The plots also received applications of nitrogen and potash. The quantities were the same for each plot.

The crops used in the test were corn, oats, wheat and hay, grown in a five and three-year rotation.

The results, as obtained so far, are summarized in Bulletin No. 110, pages 65-67, of the Ohio Experiment Station. The following are the summary tables:

TABLE 20.

Value of Average Increase From Different Sources of Phosphoric Acid.

Crops.	Culture.	Number of crops grown.	Carriers of Phosphoric Acid. Acid phosphate. Average value of increase.	Acid phosphate. Rank.	Raw bone meal. Average value of increase.	Raw bone meal. Rank.	Dissolved bone black. Average value of increase.	Dissolved bone black. Rank.	Basic slag. Average value of increase.	Basic slag. Rank.
Corn,	5-year rotations,	9	$3 23	3	$2 30	4	$3 35	2	$3 36	1
Oats,	5-year rotations,	10	3 77	2	3 71	3	4 37	1	3 71	3
Wheat,	Both rotations,	17	8 24	4	8 71	2	8 68	3	9 37	1
Hay,	Both rotations,	17	1 29	4	1 91	3	1 92	2	2 70	1

By consolidating the values given in the above table and regarding it as representing the probable outcome of an average rotation in which the four crops have followed each other as in the actual rotation, then the value of the total increase per acre due to the various sources of phosphoric acid, when supplemented with uniform amounts of nitrogen and potash, will be represented by the following figures:

	Per Acre.
Value of increase from basic slag,	$19 14
Value of increase from dissolved bone black,	18 32
Value of increase from raw bone meal,	16 63
Value of increase from acid phosphate,	16 53

Taking basic slag phosphate as 100, we find the following as the proportionate values of these materials as sources of phosphoric acid:

Basic slag phosphate,	100
Dissolved bone black,	96
Raw bone meal,	87
Acid phosphate,	87

While these results are very close together in some cases, and more work will be necessary to determine their relative value, yet there seems to be no doubt that most crops have ability to utilize phosphoric acid that is insoluble in water to a larger extent than is commonly recognized.

TEST MADE BY THE MAINE EXPERIMENT STATION.

The Maine Experiment Station has studied the availability of different sources of phosphates from two standpoints. 1st. The relative producing capacity of different forms of phosphoric acid in growing the crops commonly used in the rotation in use in that section, and 2d. Testing the relative ability of different classes of crops to use different kinds of phosphates.

The experiments conducted under the first head have had the results reported from 1886 to 1891. Since that time no results have been given in any of the Station publications. The summary of the results of the test are given in the Station Annual Report for 1891, page 129, from which the following table is copied:

TABLE 21.

Yield per Acre of Plots Fertilized with Different Forms of Phosphoric Acid, Together With Those of Plots Receiving no Phosphate.

	No manure.	Dissolved bone black 400 lbs., muriate of potash 100 lbs. and sulphate of ammonia 200 lbs. in 1886, 1887 and 1889.	Fine ground bone 300 lbs., muriate of potash 100 lbs. and sulphate of ammonia 140 lbs. per acre in 1886, 1887 and 1889.	Fine ground South Carolina rock 300 lbs., muriate of potash 100 lbs., sulphate of ammonia 200 lbs. per acre in 1886, 1887 and 1889.	Muriate of potash 100 lbs. and sulphate of ammonia 200 lbs. per acre in 1886, 1887 and 1889.	Stable manure 40,000 lbs. per acre in 1886, 1887 and 1889.
	Yield per acre—Bu.	Yield per acre—Bu.	Yield per acre—Bu.	Yield per acre—Bu.	Yield per acre—Bu.	Yield per acre—Bu.
Oats, 1886,	55.7	82.9	76.2	72.2	64.5	73.9
Oats, 1887,	26.7	38.7	31.9	35.5	35.1	34.7
Hay 1888, lbs.,	2,566	2,434	2,800	2,566	2,234	4,010
Fallow, 1889,	....	....	....	....	....	....
Peas, 1890,	12.3	15.0	15.7	14.3	12.7	22.7
Oats, 1891,	38.9	44.9	45.9	38.7	43.2	51.4
Total crop in 6 years:						
Oats,	121.3	166.5	154.0	146.4	142.8	160.0
Hay, lbs.,	2,566	2,434	2,800	2,566	2,234	4,010
Peas,	12.3	15.0	15.7	14.3	12.7	22.7

From this table it will be seen that the dissolved bone black gave the largest total yield of oats, the second largest yield of peas and the smallest yield of hay. Fine ground bone gave the largest yield of hay and peas and stood second in the yield of oats. The ground South Carolina rock stood second in hay and third in oats and peas.

It would appear from the yield of the stable manure plot that the land used was deficient in organic matter, which would account for

the falling off in the yield of the commercial manures and their lack of organic matter would probable be accountable for the insoluble phosphoric acid of the South Carolina rock falling behind. At least, the experiments reported on previous pages by other stations would indicate this fact.

EXPERIMENTS BY THE MASSACHUSETTS STATION.

The Massachusetts Experiment Station has conducted two classes of experiments with different forms and sources of phosphates. In the first test the phosphates were applied on the basis of equal money value and in the second test so as to have the same number of pounds of actual phosphoric acid per acre.

The first series of experiments were commenced in 1890 on a soil which was well exhausted of available fertility. Previous to 1887 the land had been in meadow for a number of years. This meadow was well worn out and yielded but little. From 1887 to 1890 the land was cropped in corn, Hungarian grass, cow peas, vetch and serradella, receiving no manure or fertilizer of any kind. The soil was a fair sandy loam. The following table gives the quality and analysis of the phosphates used:

TABLE 22.

Showing Schedule of Fertilizers Used in the Experiments Conducted by the Massachusetts Station.

Plot number.	Kind of Phosphate.	Per cent. total phosphoric acid.	Quantity per acre.*
†0	No phosphate,	....	....
1	Slag phosphate,	19.0	889
2	Mona Island Guano,	21.9	896
3	Florida soft phosphate,	21.7	903
4	South Carolina phosphate,	27.6	917
4	Dissolved bone black,	15.8	546

*The quantity varied from year to year with the market value.
†The no-phosphate plot was not used at the beginning of the experiment, but added in 1895.

In addition to the phosphates each plot received an application of about 300 pounds of nitrate of soda, 400 pounds potash magnesia sulphate per acre. These quantities were continued until 1893 and since that time have been made very much larger though uniform for all the plots.

The applications of phosphates were continued annually until 1893 and since that time none have been used. The object of withholding phosphate was to test their lasting effects. Subtracting the amount of phosphoric acid removed by the crops harvested from that applied, there should have remained in the soil at the end of 1901, about the following quantities of phosphoric acid per acre:

TABLE 23.

Showing Quantity of Phosphoric Acid Remaining in the Soil at the End of Ten Years Cropping.

Plot number.	Kind of Phosphate.	Pounds per acre.
1	Slag phosphate,	375
2	Mona Island Guano,	208
3	Florida phosphate,	927
4	South Carolina phosphate,	714
5	Dissolved bone black,	66

The crops which have been raised on the plots in the order of their succession are potatoes, wheat, serradella, corn, barley, rye, soja beans, Swedish turnips,* corn, oats and cabbage.

Representing the yield of the plat giving the highest return by 100, the relative efficiency of the phosphates at the beginning of 1902 stood as follows:

	Per cent.
Slag phosphates,	100.0
Ground South Carolina rock,	92.3
Dissolved bone black,	90.7
Mona Island guano,	88.3
Florida phosphate,	71.5

In 1898 these plots were all limed at the rate of one ton per acre of quick lime. The slag phosphates which contains considerable lime

*Swedish turnips were a failure on account of disease and the results of this crop were not used in computing the relative yields.

had a relatively higher efficiency than the other phosphates before the application of the lime in 1898.

Prof. H. P. Brooks in discussing the results obtained in these experiments remarks as follows: "Attention is called to the fact that the crops on these plots in recent years have not been satisfactory in amount even in the best plots. The fact that no phosphoric acid in any form has been applied during the last nine years sufficiently accounts for this relatively small yield. The results, however, indicate a relatively high degree of availability for the phosphoric acid contained in South Carolina rock and in phosphate slag. There can be no doubt that profitable crops of most kinds can be produced by the liberal use of these natural phosphates; and in a long series of years there would be a considerable money-saving in depending, at least in part, upon these rather than upon the higher-priced dissolved phosphates."

SECOND SERIES OF MASSACHUSETTS STATION.

In the second set of tests of phosphates the application has been made so as to give each plot the same quantity (96 lbs. per acre), actual phosphoric acid. The plots so far have had annual applications. In addition to the phosphoric acid, each plot has received, yearly, nitrogen at the rate of 52 lbs. per acre and potash at the rate of 152 pounds per acre. This test has been in progress four years and has been cropped as follows: Corn, cabbage, corn and in 1900, two crops harvested, oats, hay and Hungarian grass hay.

The following are the kinds of phosphates used in this test:

Plot No.	Kinds of Phosphate.
1,	No phosphate.
2,	Apatite.
3,	South Carolina rock.
4,	Florida soft phosphate.
5,	Slag phosphate.
6,	Tennessee rock.
7,	No phosphate.
8,	Dissolved bone black.
9,	Raw bone.
10,	Dissolved bone black.
11,	Steamed bone meal.
12,	Dissolved phosphate rock.
13,	No phosphate.

No details of yields for each year have been reported, but the results so far have been stated by Prof. Brooks as follows:

1. The slag phosphate evidently furnishes phosphoric acid in an exceedingly available form, the yield being almost equal to dissolved bone black.

2. Florida soft phosphate is apparently a very inferior material, the phosphoric acid evidently becoming available only with great slowness.

3. Steamed bone meal appears to be inferior in availability to raw bone meal.

TESTING THE RELATIVE ABILITY OF DIFFERENT CROPS TO USE VARIOUS FORMS AND SOURCES OF PHOSPHATES.

This is a subject which has been given considerable attention by the Maine and Cornell Experiment Stations. The study has been conducted both in the field and in pot experiments.

These experiments, which have been made in the pots or boxes with sand and artificial soils, while instructive in showing the relative ability of different plants to use various phosphates, yet they have been conducted under such abnormal conditions that the results obtained can not be applied in regular field practice. Particularly is this true in the use of the insoluble phosphates which have been found to be most available upon soils which contained considerable organic matter.

The first test conducted by the Maine Station was made in the field on the farm of H. L. Leland, at East Sangerville, on a slaty gravel soil. The detailed results of this test are given in the Annual Report of that Station for 1891, page 142. Part of the growing season was very dry, which materially interfered with the yields obtained and no doubt to some extent with the results in general.

The following table shows the crops and phosphates used in the test, with the results obtained:

TABLE 24.

Showing Plants and Fertilizers Used and Results of the Same in Testing the Ability of Plants to use Different Phosphates.

Crop.	500 Lbs. Dissolved Bone Black and 100 Lbs. Nitrate of Soda per Acre.	1,000 Lbs. South Carolina Rock and 100 Lbs. Nitrate of Soda per Acre.	500 lbs., Caribbean Sea Guano and 100 Lbs. Nitrate of Soda per Acre.
Plot 1—Clover,	Fair,	Best at close of season,	Very poor.
Plot 2—Oats,	Total crop, 115 lbs.,	Total crop, 80 lbs.,	Total crop, 75 lbs.
Plot 3—Peas,	Total crop, 105 lbs.,	Total crop, 110 lbs.,	Total crop, 51 lbs.
Plot 4—Turnips,	Total crop, 351 lbs.,	Total crop, 369 lbs.,	Failure.
Plot 5—Wheat,	Total crop, 120 lbs.,	Total crop, 105 lbs.,	Total crop, 65 lbs.
Plot 6—Beans,	Total crop, 63 lbs.,	Total crop, 62 lbs.,	Total crop, 54 lbs.
Plot 7—Potatoes,	228 lbs.,	210 lbs.,	153 lbs.
Plot 8,			
Plot 9—Corn,	Failure,	Failure,	Failure.
Plot 10—Barley,	Total crop, 80 lbs.,	Total crop, 75 lbs.,	Total crop, 64 lbs.
Plot 1d—Clover,	Fair,	Best at close of season,	Very poor.
Plot 2d—Oats,	Total crop, 111 lbs.,	Total crop, 83 lbs.,	Total crop, 70 lbs.
Plot 3d—Peas,	Total crop, 97 lbs.,	Total crop, 103 lbs.,	Total crop, 52 lbs.
Plot 4d—Turnips,	Total crop, 340 lbs.,	361 lbs.,	Failure.
Plot 5d—Wheat,	Total crop, 119 lbs.,	Total crop, 102 lbs.,	Total crop, 61 lbs.
Plot 6d—Beans,	Total crop, 66 lbs.,	Total crop, 72 lbs.,	Total crop, 43 lbs.
Plot 7d—Potatoes,	223 lbs.,	211 lbs.,	146 lbs.
Plot 8d,			
Plot 9d—Corn,	Failure,	Failure,	Failure.
Plot 10d—Barley,	Total crop, 77 lbs.,	Total crop, 78 lbs.,	Total crop, 62 lbs.

An examination of the yields of the different crops shows that the dissolved bone black has given, with the majority of them, the largest return and the Caribbean sea guano the least.

With peas and turnips South Carolina rock seems to have been more effective than dissolved bone black. This point is brought out quite sharply. The fact that turnips respond to manuring, with some crude phosphate, has been noted by other experimenters.

The results obtained in this experiment with South Carolina rock on peas agree very closely with the results obtained from all other experiments made by the Station covering this point.

Box or pot experiments upon this subject have been in progress at the Maine Station for some years. This work was started by Prof. Walter Balantine and continued by him until his death; since that time the work has been continued by Prof. L. H. Merrill. The first report upon the subject was made in the annual report for 1893, and the last reported up to this time is in the report for 1898, page 64. The following description of the plan of the experiment and the results obtained are copied from the Fourteenth Annual Report of the Maine Station, pages 66 to 74:

PHOSPHATES USED IN BOX EXPERIMENTS.

In the experiments here recorded, three forms of phosphates were used.

1. Acid Florida Rock.—This was prepared by treating a Florida phosphatic rock with sulphuric acid, thereby converting a large part of the phosphate into an available form. At the beginning of the first experiment this phosphate had the following composition: 20.60 per cent. total phosphoric acid, of which 16.90 per cent. was available (19.97 per cent. soluble, 1.93 per cent. citrate soluble). In the later work it was found that the composition had changed somewhat, but the amount of available phosphate remained about the same.

2. Crude, finely ground Florida rock (floats), containing 32.88 per cent. total phosphoric acid, none of which was soluble, with only 2.46 per cent. soluble in ammonium citrate. This was obtained from the commercial ground rock by stirring it with water, allowing the coarse particles to subside and then pouring off the turbid water. The "floats" used in this experiment consisted of the sediment deposited from these washings.

3. A phosphate of iron and alumina (Redonda). The first sample used contained 49.77 per cent. phosphoric acid, a large part of which, 42.77 per cent. was soluble in ammonium citrate. The Redonda underwent such rapid changes in the intervals between the experiments that it became necessary to prepare fresh quantities at each successive planting. The analysis given above is fairly representative of all.

Twenty grains of the floats, containing 6.58 grains total phosphoric acid, were used for a single box. The other phosphates used were first analyzed and such quantities used for each box that the total quantity present was in each case the same, 6.58 grams. The actual amount of available phosphoric acid thus supplied to each box by the various phosphates were: By the acid rock, 5.39 grams; by the floats, .49 grams; by the Redonda, 5.67 grams.

DETAILS OF THE EXPERIMENT.

The experiments were conducted in one of the green-houses, the plants being grown in wooden boxes, fourteen inches square and twelve inches deep. When filled to within one and one-half inches of the top, the boxes contained 120 pounds of sand. The sand used was taken from a knoll near the river, at a depth of three or four feet, and was nearly free from organic matter. Traces of phosphoric acid were present, but this was in the insoluble form, and the quantity in each box was the same, its presence is not considered objectionable. The sand was carefully screened before being used, and thoroughly mixed with the phosphates and other plant foods.

In each period twelve boxes were used for each kind of plant. In the first box the acid rock was used; in the second, the un-

treated Florida rock, or "floats;" in the third, the phosphate of iron and alumina, or Redonda; the fourth box received no phosphate. The next four boxes were treated in the same manner and so on to the end. Thus, it will be seen that for each kind of plant there were three boxes which received exactly the same treatment In addition to the phosphates, each box received ten grams sodium nitrate, five grams potassium chloride and five grams magnesium sulphate. In the boxes where the Redonda was used, ten grams calcium sulphate were also added. It was intended to supply all the elements essential to the healthy development of the plants, except that every fourth box receivd no phosphate. All the other conditions were made as uniform as possible in order that the differences in growth might fairly be attributed to the differences in phosphates used.

KINDS OF PLANTS GROWN.

Eighteen species of plants were chosen, representing seven orders: Peas, horse beans, clover and alfalfa (Leguminosae); turnips, rutabagas, cauliflower and kohl-rabi (Crusiferae); barley, corn, oats and timothy (Graminae); tomatoes and potatoes (Solanaceae); carrots and parsnips (Umbelliferae); buckwheat (Polygonaceae); sunflowers (Compositae).

It was intended to carry each plant through three periods of growth, but the clover, the common red species (T. pratense), could not be matured in the time required for the other plants, and but two crops were grown. The sunflower and buckwheat did not thrive under the conditions of the experiment, and after a single trial were replaced by carrots and parsnips, which were grown for the two following periods. The seed was carefully selected, that only being used which was well formed and of uniform size. Of the larger plants, four or five were grown to each box. The smaller plants were thinned so that the number to each box was uniform for that plant. Such leaves as ripened before the plants matured were removed, dried and added to the plants when harvested. No attempt was made at the pollination. As very few insects were present during the growth of the plants, the fruiting, as might have been expected, was very irregular. As soon as the plants seemed to have attained their maximum development, they were harvested, dried, weighed and the total amount of dry matter determined for each crop grown. In the diagrams that follow the average production for a single period is shown, the heavy lines representing the relative weights of dry matter, and the last column the weights in grams.

TABLE 25.

Diagram Showing Relative Weights of Dry Matter of Plants Grown With Phosphoric Acid From Different Sources.

Crops.	Phosphate.	Comparative Scale.	Weight—grams.
Peas,	Acid rock,		167
	Floats,		122
	Redonda,		94
	No phosphate,		87
Horse beans,	Acid rock,		269
	Floats,		128
	Redonda,		118
	No phosphate,		86
Clover,	Acid rock,		217
	Floats,		169
	Redonda,		126
	No phosphate,		83
Alfalfa,	Acid rock,		107
	Floats,		97
	Redonda,		87
	No phosphate,		90
Turnips,	Acid rock,		222
	Floats,		202
	Redonda,		187
	No phosphate,		119
Rutabagas,	Acid rock,		152
	Floats,		145
	Redonda,		122
	No phosphate,		64
Cauliflower,	Acid rock,		176
	Floats,		167
	Redonda,		107
	No phosphate,		62
Kohl-rabi,	Acid rock,		232
	Floats,		209
	Redonda,		172
	No phosphate,		130
Barley,	Acid rock,		338
	Floats,		171
	Redonda,		186
	No phosphate,		146
Corn,	Acid rock,		218
	Floats,		85
	Redonda,		98
	No phosphate,		31
Oats,*	Acid rock,		662
	Floats,		307
	Redonda,		380
	No phosphate,		319
Timothy,	Acid rock,		410
	Floats,		329
	Redonda,		346
	No phosphate,		353

TABLE 25—Continued.

Crops.	Phosphate.	Comparative Scale.	Weight—grams.
Tomatoes,	Acid rock,		135
	Floats,		92
	Redonda,		79
	No phosphate,		36
Potatoes,	Acid rock,		260
	Floats,		187
	Redonda,		156
	No phosphate,		151
Carrots,	Acid rock,		214
	Floats,		141
	Redonda,		149
	No phosphate,		135
Parsnips,	Acid rock,		237
	Floats,		151
	Redonda,		155
	No phosphate,		163
Buckwheat,	Acid rock,		107
	Floats,		54
	Redonda,		51
	No phosphate,		37
Sunflowers,	Acid rock,		101
	Floats,		14
	Redonda,		15
	No phosphate,		11
Turnips, roots,	Acid rock,		100
	Floats,		70
	Redonda,		90
	No phosphate,		44
Rutabagas, roots,	Acid rock,		62
	Floats,		47
	Redonda,		32
	No phosphate,		16
Cauliflower, edible portion.	Acid rock,		50
	Floats,		19
	Redonda,		......
	No phosphate,		......
Kohl-rabi, edible portion,	Acid rock,		153
	Floats,		129
	Redonda,		92
	No phosphate,		60
Potatoes, tubers,	Acid rock,		185
	Floats,		131
	Redonda,		140
	No phosphate,		115
Carrots, roots,	Acid rock,		173
	Floats,		109
	Redonda,		113
	No phosphate,		102
Parsnips, roots,	Acid rock,		196
	Floats,		115
	Redonda,		114
	No phosphate,		120

*In the case of the oats and timothy the scale has been reduced one-half to accommodate the lines to the space allowed. The relative length of the lines for the same plant has been maintained.

RESULTS OF THE MAINE STATION EXPERIMENTS.

In every case the acid rock gave the best returns. The gain was especially marked with the family Gramineae, three members of which, the barley, corn and oats, yielded nearly double the amount produced by either the floats or Redonda. The effect upon the sunflowers and buckwheat was especially marked, but if these plants could have been brought to full development it is probable the gain would have been less apparent.

If we compare the amount of dry matter produced by the acid rock with that produced by the floats for all the crops grown, we find the balance in favor of the acid rock to be 52 per cent. In other words, the effect of the available phosphoric acid, as compared with the insoluble phosphate, was to increase the product more than one-half.

In nearly every case the floats gave results second only to those obtained with the acid rock. With this phosphate the Cruciferae gave returns within ten per cent. of those obtained by the acid rock. This is not true of the edible portion of these plants, however, for there the good effects of the acid rock were more marked.

Of the three forms of phosphate used, the Redonda proved the least valuable, though supplying a larger amount of available phosphoric acid than the floats. In most cases, it showed itself inferior even to floats. The Germineae furnished an interesting exception to this rule, yielding results with Redonda above those given by the floats.

The small yield from the boxes in which no phosphate was used is sufficient indication of the extreme poverty of the soil, and confirms the belief that the amount of phosphoric acid thus supplied is not sufficiently large to seriously affect the experiment.

It is interesting to note that the plants of the same family show a remarkable agreement in their behavior towards the various phosphates. The striking manner in which the Gramineae respond to the stimulus of the acid rock has already been alluded to. In no other case is the effect so marked. Another peculiarity of the members of this family is shown in their conduct toward the Redonda. The relative value of this phosphate and floats is here the reverse of that shown by nearly all the other plants. The failure of the Cruciferae to respond to the acid rock furnishes a good illustration of a similar kind. The Umbelliferae, though responding to the acid rock, seem to derive no benefit from either the floats or Rendonda, since neither of the phosphates increase the yield above that obtained where no phosphates were used. This is true both of the whole plant and the roots.

The alfalfa shows a strange indifference to the precise form in which the phosphoric acid is supplied. The crop was light in every case, and the phosphoric acid already present in the barren soil used, seems to have sufficed for the slender product.

STIMULATING EFFECT OF ACID PHOSPHATE IN THE EARLY STAGES OF GROWTH.

A report of this work would be incomplete if it failed to take note of certain facts observed in the course of the experiment which cannot be shown in the diagram, where only the final results are given.

Throughout the whole series of experiments the effect of the acid rock was marked, the plants receiving it in nearly every case at once taking the lead, and keeping it to the end. The horse-beans furnish a marked exception to this rule, the more nearly equal development being perhaps due to the large amount of nutriment stored in the seed. When this supply was exhausted, the phosphoric acid hunger manifested itself.

In by far the larger number of cases, especially with the clover, timothy, turnips and rutabagas, the good effects of the acid rock were more marked during the first few weeks of growth than at a later stage, when the roots become more fully developed, and had begun to forage for themselves. This fact, also, is shown in the figures of the clover and timothy. It would appear that the young plants feed but little upon the insolnble phosphates, but that the organic acids present in the sap of the roots exert a solvent action upon the insoluble phosphates in the soil, gradually converting them into available forms.

It will be noticed that in this work only the immediate effect of the phosphates has been taken into consideration, no mention having been made of the unused phosphoric acid remaining in the soil at the close of the experiment. In actual field work, the good effect of the ground rock would, of conrse, be far more lasting than that of the acid rock.

Box experiments were made at the New Hampshire Experiment Station in 1893, with winter rye, the phosphoric acid being supplied by roasted Redonda, ground bone and basic slag. The result showed that the rye gave nearly as good returns with the roasted Redonda as with the other phosphates. The result confirms the work here reported. It will be seen by reference to the diagram here given that the corn, barley, oats and timothy (plants closely related to rye) gave better results with the Redonda phosphate than with the finely ground Florida rock.

SUMMARY OF THE MAINE STATION EXPERIMENTS.

1. Plants differ in their ability to feed upon crude phosphates.
2. Turnips, rutabagas, cauliflowers and kohl-rabi gave nearly as good returns with the Florida rock as with the acid rock.
3. In every other case the good effect of the acid rock was very marked.
4. In most cases the crude Florida rock yielded better returns than the Redonda.
5. Barley, corn and oats seem to require an acid (soluble) phosphate.
6. When early maturity is desired, the acid rock can profitably be used.
7. The largely increased production obtained by the use of the acid rock will often determine the success of the crop.
8. The solubility of a phosphate in ammonium citrate is not always the correct measure of its actual value to the plant.

TESTS MADE BY THE CORNELL UNIVERSITY EXPERIMENT STATION.

In the winter of 1900-1901 some experiments were conducted at the Cornell Experiment Station upon the relative ability of various orders of plants to utilize different sources and forms of phosphoric acid. These tests were conducted in a green-house and the plants grown in box pots. The soil in which the plants were grown was a white quartz sand prepared by grinding quartz rock. The soil or medium furnished practically no plant food, so that it was necessary to furnish an artificial supply of the essential plant foods. All conditions were made exactly similar except as to the kind of phosphoric acid supplied. The actual amount of phosphoric acid supplied the different boxes was the same, but the sources were different.

The following table gives the variety of plants used, the source of phosphoric acid supplied and the results obtained:

TABLE 26.

Diagram Showing Relative Weights of Dry Matter of Plants Grown With Phosphoric Acid From Different Sources.

Order.	Crop Grown.	Phosphate Used and Comparative Scale of Product.	Weight in grams of dry matter.
Leguminoseae,	Clover,	Acid phosphate	30.6
		Bone black	32.3
		Basic slag	15.7
		Floats	1.45
		No phosphoric acid	2.35
	Peas,	Acid phosphate	21.78
		Bone black	22.32
		Basic slag	9.95
		Floats	9.76
		No phosphoric acid	11.73
Cruciferae,	Rape,	Acid phosphate	20.74
		Bone black	18.94
		Basic slag	17.54
		Floats	23.39
		No phosphoric acid	3.51
	Radishes,	Acid phosphate	15.15
		Bone black	14.1
		Basic slag	12.8
		Floats	7.
		No phosphoric acid	1.75

TABLE 26—Continued.

Order.	Crop Grown.	Phosphate Used and Comparative Scale of Product.	Weight in grams of dry matter.
Graminae.	Oats,	Acid phosphate	36.91
		Bone black	37.93
		Basic slag	24.46
		Floats	17.71
		No phosphoric acid	13.14
	Barley,	Acid phosphate	18.2
		Bone black	25.75
		Basic slag	21.6
		Floats	3.22
		No phosphoric acid	5.99
Umbelliferae.	Parsnips.	Acid phosphate	24.93
		Bone black	32.18
		Basic slag	5.78
		Floats	.69
		No phosphoric acid	.44

The results obtained by the tests of both the Maine and Cornell Experiment Stations are valuable in that they show the relative ability of plants of various kinds to feed upon the different forms of phosphoric acid. These results also show that upon soils which are deficient in organic matter it is decidedly best with most crops to use some phosphate furnishing soluble phosphoric acid. Nevertheless, these results seem to point out that the insoluble phosphates might be used on quite barren soils to grow such crops as turnips or rape for soil renovation or green manure purposes.

Again, these results, when considered in connection with the results of field experiments made upon soil which contained a fair amount of organic or vegetable matter, would seem to give additional evidence as to the necessity of having lands full of organic matter in order to obtain good results from applications of insoluble phosphates.

SOME FOREIGN EXPERIMENTS WITH PHOSPHATES.

Numerous experiments have been made from time to time upon different phases of points effecting the availability of phosphates and forms of phosphoric acid. To give an abstract from all of these tests would not be possible in a work of this kind, yet it might be interesting to note briefly a few which have been repeated recently and which would seem to be closely related to the tests made in this country.

Experiments on the relative value of different phosphates, by Dimitry Prianischnihoff (Vol. 56 (1901), pp. 107-146, Landw. Versuchs-Stationen).

This was also a test of the relative ability of various crops to use sparingly soluble phosphates. The tests were made by pot culture in sand. The following numbers indicate the relative amounts of phosphoric acid assimilated as shown by the results up to the time of making the report:

	Phosphorite.	Bone meal.	Basic slag.	Ca HPO_4.
Cereals,	0-10	40	60-70	100
Buckwheat, lupens, etc.,	60	90	100	100

The summary makes the following statements:

Phosphorite should not be applied to light soils (probably not to any soil long cultivated) for cereals, but only for buckwheat, mustard, lupens and peas. In the case of peat or muck land, however, and acid soils generally, phosphorite may be applied for any crop. An experiment on black soil is recorded in which, without manure, buckwheat gave more produce than wheat; the addition of phosphorite and of sodium di-hydrogen phosphate greatly increased the yield of wheat but not of buckwheat. This is attributed to the ability of buckwheat to make use of sparingly soluble phosphoric acid. Experiments are also described upon the use of various ammonium salts in conjunction with the phosphates, and the results showed that they acted as solvents and made the phosphoric acid available.

THE USE OF PHOSPORITE AND GREEN MANURING.

Some experiments on this subject were conducted by A. N. Engelhardt, which are abstracted in Chem. Centralblat, 1901, p. 232. The following were the results obtained from three year's field experiments: The fine-ground untreated phosphate was especially effective on cereals. The effects was best on soils containing an abundance of organic matter. The finer the meal and the greater the percentage of phosphate of lime the more effective was the phosphate. The best results were obtained with rye, but the following crop of oats was also benefited. When the phosphorite was applied to rye, oats or flax, and these crops followed by a crop of rye, to which barnyard manure was applied, the yield of the latter was much better than of rye which had received only an application of barnyard manure.

The results showed that ground phosphorite can be profitably used to supply phosphoric acid on soils which contain a sufficient amount of nitrogen, potash and lime. When its action lessens, green manuring should be resorted to. Lime and marl used in conjunction with the phosphorite was advantageous.

CONCLUSION.

In conclusion, it may be said that there are many more experiments that might be referred to which have covered the same points already considered, and many others which have had to do with particular phosphates, but that it is needless to go over them in detail as the results are, in most instances, practically the same as those already cited and are simply confirmatory of the statements which have been made from time to time in this Bulletin.

The experiments which have been quoted from show that many of the popular notions regarding phosphates are not fully warranted

and that much of our daily practice is either based upon pre-conceived ideas or been moulded by such information as has been given out which would serve the interest of fertilizer manufacturers. It is certain that a careful study of the results of the experiments given in the preceding pages will make it evident to all that there is more need of a careful study of the character of land to which the phosphate is to be applied and then to use the form of phosphoric acid and other accessory measures which will gain the desired results most economically.

REVIEW OF THE RESULTS OF THE EXPERIMENTS.

All of the experiments which have been conducted upon the use of phosphoric acid in agriculture have given results which seem to warrant the general statement that much of the practice now followed in the use of phosphates is not founded upon facts; but are probably backed either by the tradition and statements gathered from the customs of our forefathers or promulgated by the teachings of the commercial world. The latter, in many cases, are much colored for the sake of self preservation and financial gain.

There is no doubt but that the first step in the economical use of phosphates is to imitate nature and endeavor to keep the soil well supplied with organic matter; for it is only by such means that the phosphates contained in the soil naturally and those applied artificially can be fully utilized by the cultivated crops.

It is very evident from all the tests cited that some crops, particularly the turnip family, have a greater ability than others to use crude or insoluble phosphates and these experiments would certainly teach that the aim should be to employ such crops for rendering insoluble phosphates available and by such a practice save much that is now being spent for sulphuric acid and the cost of manufacturing the soluble phosphates.

The experiments, in most instances, show that the presence of carbonate of lime is of considerable advantage in increasing the availability of phosphates.

Some of the tests show that the iron and alumina phosphates are much more valuable as plant foods than is generally considered, in fact under some circumstances they seem to be as soluble and even superior to lime phosphates.

In regard to the so-called available phosphoric acid of commercial fertilizers, the results all point to the fact that there is no difference in it depending upon its source; that is, a pound of available phos-

phoric acid from a mineral source is just as valuable as a pound from an organic source. With this fact confronting us there seems to be nothing to warrant the purchase of a dissolved bone instead of a dissolved rock, unless the phosphoric acid in the bone costs no more than that in the rock. In other words, a farmer can not afford to pay more per pound for available phosphoric acid in dissolved bone than he can for that in dissolved rock any more than he would pay more for sugar from cane than he would for sugar from beets. In either case the only justification that could be given would be that there was no departure from the traditions of his grandfathers.

The results of both of field and plot experiments show that certain classes of phosphates are more available and hence have a higher agricultural value than would be given them by official methods of analysis. This condition would seem to warrant some modified method for analyzing such materials. This is particularly true of the tetra-phosphates when used on some soils.

The best advice and general rule which can be given in the matter of the intelligent use of phosphates is, to study the special conditions that surround the particular case in hand, observe the methods of nature and compare these circumstances with those of the experiments given, then apply the results with such modification as good common sense would seem necessary to meet the demands of local conditions.